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FINAL REPORT

on the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MULTIDISCIPLINARY RESEARCH PROGRAM
IN SPACE SCIENCE AND TECHNOLOGY

at the

UNIVERSITY OF ARIZONA

Period covered

June 1, 1967 to September 30, 1970

September, 1970

Submitted by

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of Research

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INTRODUCTION

The step-funded NASA Institutional Grant -- initially funded in December, 1966 -- was employed to strengthen a variety of space related programs at the University of Arizona. It was administered by a four-man committee of scientists previously appointed by the President of the University and charged with the responsibility for developing the Space Science Program on campus.

In discharging its responsibility to administer the institutional grant in such a way as to initiate and strengthen space related research, the committee invited proposals from all departments of the University that might have an interest in participating in space related scientific programs. From the numerous proposals received, 81 grants -- ranging in value from $562 to $49,750 with a mean value of $6,402 -- were ultimately awarded.

During the early stages of the program, the committee gave emphasis to the support of two types of research efforts: 1) those that would facilitate the development of new investigators; and 2) those that would provide established investigators with greater flexibility, thereby allowing them to work more quickly and encouraging them to initiate new areas of inquiry.

As the program evolved, a greater emphasis was placed on highly meritorious projects in well established research efforts that deserved support to generate initial findings which could be used in obtaining project support, to continue efforts where grants were pending, or to carry to completion partially funded programs that might not otherwise have provided answers to provocative questions. For example; one grant was awarded to extend and complete investigations, funded by a NASA project grant, designed to determine the existence of a significant and consistent relationship between solar activity and tree-ring growth.

In many instances relatively small grants made possible the construction of equipment essential for preliminary investigations which led to the development of proposals for project support. In others, however, grants were made for projects that entailed an essential measurement or investigation, but which were not expected to lead to continuing efforts.

Illustrative of grants of this type were Kuiper's interferometer studies of the spectra of Venus showing the atmosphere of Venus to be practically devoid of water vapor, a finding that was supported by the subsequent probe flight of the Russians. In a few short months Bashkin obtained very significant results on the spectra of noble gases; Fernando developed a new method for obtaining the reflectace and absorption spectra of metal complexes; Low determined the sun's brightness at one mm; and Korn produced a number of devices for the hybrid computer and a display system for small digital computers.

In the later years, the committee concentrated on the use of grant funds to supplement University funds allocated to programs considered to be essential to its on going educational and research efforts, to continue the support of previously funded projects, and to the acquisition of equipment essential for the development of teaching and research facilities that produced and are continuing to produce substantial benefits for faculty and students alike.

Throughout its life the institutional grant was used in support of the educational objectives of the University. Students were involved directly as research assistants and many more less directly in research leading to graduate degrees. In addition to the more than 40 students who received direct financial support, a much larger number of students -- including some who have yet to enroll -- have and will benefit from the equipment acquired and the research findings generated which can be extended and/or refined as part masters or doctoral theses. At the time final reports of the grants were issued, this institutional grant had contributed directly to the completion of eleven M.S. and seven Ph.D. degrees.

There can be no question that the Institutional Grant contributed significantly to the development of the Space Science program at the University of Arizona and through this development to the extension of knowledge dealing with space related subjects.

The projects funded had produced the material for some eighty-two papers, eleven M.S. theses, seven Ph.D. theses and many speeches at the time final reports were submitted. But of even greater importance, the grant program made a substantial contribution to the creation of strong and lasting research and educational complexes. The program contributed significantly to the development of the Lunar and Planetary Laboratory as a major center of excellence that has and is continuing to make important contributions to space science. Its scope has now been broadened by the creation of a new educational element, the Department of Planetary Science. The Optical Science Department, which has developed as a major educational, research, and technology transfer element of the University, received timely support that would not have been forthcoming had it not been for the existence of the institutional grant program.

By their very nature, institutional grants provide universities with opportunities to expedite the development of their research capabilities and individual faculty members with means by which their potential for research can be more fully exploited.

The utility of the institutional-type grants as supplements to project support has been demonstrated rather clearly in our experience. Three programs for which project support was not immediately available and which were initially funded through the institutional grant program have since attracted national and international attention. These programs, by the way, are now well funded.

We firmly believe that institutional grant programs enjoy certain real advantages over project grants. When combined in an appropriate mix, the two types of programs can help to ensure the full and effective utilization of university resources.

The main body of this report includes a list of awards made under the grant, their distribution among various departments, and the final reports of those grants that have not been included in the various reports submitted previously.

TABLE I

Grant No.	Investigator	Department	Grant	Date of Award
1	Stuart Hoenig	Aerospace & M.E.	$ 4,200	6-15-66
2	Robert DuBois	Geology	5,000	6-15-66
3	John Sumner	Geology	5,000	6-15-66
4	Robert Lansing	Psychology	5,000	6-15-66
5	Lee Jones	Chemistry	1,670	6-15-66
6	Monte Davis	Nuclear Engr.	5,000	9-15-66
7	Morton Wacks	Nuclear Engr.	5,000	6-15-66
8	James Melsa	Electrical Engr.	5,000	6-15-66
9	Robert Waland	Lunar & Planetary Lab	4,000	6-15-66
10	Louis Demer	Metallurgy	5,000	6-15-66
11	Granino Korn	Electrical Engr.	10,000	6-15-66
12	Cecil Rogers	Psychology	5,000	6-15-66
13	Stephen Jacobs	Optical Sciences	5,000	6-15-66
14	George Tyras	Electrical Engr.	5,000	6-15-66
15	Frank Low	Lunar & Planetary Lab	6,000	6-15-66
16	E. W. Whitaker	Lunar & Planetary Lab	1,000	6-15-66
17	D. Cruikshank	Lunar & Planetary Lab	4,500	6-15-66
18	Donald Taylor	Astronomy	6,000	6-15-66
19	Donald McEligot	Aerospace & M.E.	4,000	6-15-66
20	Roger Jones	Electrical Engr.	5,000	6-15-66
21	Stanley Bashkin	Physics	10,800	7-12-66
22	Quintus Fernando	Chemistry	6,200	7-12-66
23	James McDonald	Meteorology	1,300	7-15-66
24	Robert Carlile	Electrical Engr.	6,000	9-6-66

TABLE I (Cont'd)

Grant No.	Investigator	Department	Grant	Date of Award
25	Louis Demer	Metallurgy	3,000	11-1-66
26	Gerard Kuiper	Lunar & Planetary Lab	27,615	12-19-66
27	Louis Demer	Metallurgy	2,500	12-19-66
28	John Kessler	Physics	7,000	3-1-67
29	Gerard Kuiper	Lunar & Planetary Lab	2,000	4-1-67
30	Alan Binder	Cancelled	---	---
31	Neil Cox	Chemical Engr.	9,500	5-1-67
32	Thomas Gehrels	Lunar & Planetary Lab	2,490	5-1-67
33	Gerard Kuiper	Lunar & Planetary Lab	15,000	5-15-67
34	Stephen Jacobs	Optical Sciences	8,100	5-15-67
35	Gerard Kuiper	Lunar & Planetary Lab	49,750	7-7-67
36	Granino Korn	Electrical Engr.	12,940	7-13-67
37	Taylor-Westerlund	Astronomy	27,150	7-13-67
38	Monte Davis	Nuclear Engr.	7,650	7-13-67
39	C. A. Rogers	Psychology	1,010	7-7-67
40	Stuart Hoenig	Electrical Engr.	900	10-14-67
41	John Poulous	Optical Sciences	5,896	10-14-67
42	Reagan/Herman	Atmospheric Physics	10,400	10-13-67
43	Lee Jones	Chemistry	2,000	10-13-67
44	Keaton Keller	Nuclear Engr.	5,500	10-21-67
45	Bryant Bannister	Tree Ring Lab	11,405	11-4-67
46	Not used			
47	Vern Johnson	Electrical Engr.	3,500	1-4-68
48	Thomas Gehrels	Lunar & Planetary Lab	760	2-15-68

TABLE I (Cont'd)

Grant No.	Investigator	Department	Grant	Date of Award
49	Dale Cruikshank	Lunar & Planetary Lab	1,479	3-3-68
50	A. Meinel	Optical Sciences	10,000	3-3-68
51	Donald McEligot	Aerospace & M. E.	4,520	5-6-68
52	Paul Skinner	Auditory Res. Lab	3,400	5-6-68
53	W. K. Hartmann	Lunar & Planetary Lab	2,008	5-7-68
54	Thomas Gehrels	Lunar & Planetary Lab	5,720	6-13-68
55	D. J. Hamilton	Electrical Engr.	10,000	7-10-68
56	R. M. Kalbach	Physics	7,500	7-10-68
57	John Kessler	Physics	7,313	6-13-68
58	R. H. Chambers	Physics	4,500	10-7-68
59	John O. Stoner	Physics	3,000	10-7-68
60	G. V. Coyne	Lunar & Planetary Lab	1,146	10-8-68
61	Thomas Gehrels	Lunar & Planetary Lab	1,715	10-8-68
62	Keaton Keller	Nuclear Engr.	1,430	11-6-68
63	Bartholemew Nagy	Geochronology	10,000	12-5-68
64	Uwe Fink	Lunar & Planetary Lab	9,500	1-20-69
65	L. K. Schneider	Anatomy	3,000	1-28-69
66	R. H. Chambers	Physics	4,500	3-12-69
67	John O. Stoner	Physics	2,000	3-12-69
68	H. C. Perkins	Aerospace & M. E.	5,000	3-12-69
69	Gerard Kuiper	Lunar & Planetary Lab	30,000	3-12-69
70	L. C. Schooley	Electrical Engr.	4,880	6-2-69
71	Granino Korn	Electrical Engr.	2,250	6-2-69
72	William Tifft	Astronomy	1,500	6-2-69

TABLE I (Cont'd)

Grant No.	Investigator	Department	Grant	Date of Award
73	Vern Johnson	Electrical Engr.	4,750	7-8-69
74	Uwe Fink	Lunar & Planetary Lab	5,800	7-6-69
75	Thomas Gehrels	Lunar & Planetary Lab	1,600	7-8-69
76	A. Meinel	Optical Sciences	2,300	7-9-69
77	Gerard Kuiper	Lunar & Planetary Lab	20,000	12-19-69
78	Randic-Cruikshank	Lunar & Planetary Lab	3,280	12-23-69
79	Carlile-Johnson	Electrical Engr.	2,370	12-23-69
80	G. T. Sill	Lunar & Planetary Lab.	1,065	12-23-69
81	G. Van Biesbroeck	Lunar & Planetary Lab	2,200	3-11-70
82	Gerard Kuiper	Lunar & Planetary Lab	562	3-11-70
83	Harold Larson	Lunar & Planetary Lab	1,500	3-11-70
		Total Awards	$518,524	

TABLE II

Department	No. of Grants	Total Amounts
Aerospace - Mech Engr	4	$ 17,720
Anatomy	1	3,000
Astronomy	3	34,650
Atmospheric Physics	1	10,400
Auditory Research Lab	1	3,400
Chemical Engineering	1	9,500
Chemistry	3	9,870
Electrical Engr	13	72,590
Geochronology	1	10,000
Geology	2	10,000
Lunar & Planetary Lab	25	200,690
Metallurgy	3	10,500
Metecrology	1	1,300
Nuclear Engr	5	24,580
Optical Sciences	5	31,296
Physics	8	46,613
Psychology	3	11,010
Tree Ring Lab	1	11,405
TOTAL	81	$518,524

Grant Number 1. June 15, 1966 $4,200

Investigator Stuart A. Hoenig, Associate Professor
Aerospace and Mechanical Engineering Department

Title: A New Detector for Astronomical Studies

Summary:

This research project has been completed. Final Report was included in the third Semiannual Report.

Grant Number 2. June 15, 1966 $5,000

Investigator Robert L. DuBois, Professor
Geology Department

Title: Magnetic and Petrographic Studies of Meteorites and Other Extra-Terrestrial Materials

Summary:

This project concerns research designed to investigate the magnetic properties of meteorites and to interpret them with regard to primitive magnetic fields associated with their parent planets. In addition, this research will provide basic data for interpreting magnetic measurements made in situ on other planets.

Research activity has continued in the investigation of the magnetic properties of meteorites. Instruments have been constructed or bought to handle the meteorites. Measurements have been made of direction and intensity of remanent magnetism on twenty-four specimens, and thermal magnetic properties have been determined. Considerable effort was expended in the study of the stony meteorites and much new data was accumulated. This data has been compared with other known data. This program is a cooperative effort by Professor DuBois of the University and Donald P. Elston of the Astro-Geology Branch of the United States Geological Survey. New data is being acquired concerning other meteorite classes, but the primary emphasis is placed on the fundamental magnetic properties of the ferro-magnetic minerals of meteorites and the interpretation of the conditions of acquisition of magnetism by meteorites.

Publications:

Article to be published: "Remanent Magnetism in Meteorites"

Grant Number 3. June 15, 1966 $5,000

Principal Investigator John S. Sumner, Professor
Department of Geology

Title: Geophysical Evaluation of Terrestrial Meteorite Impact Locations

Summary:

The objective of the geophysical study was to determine if the induced polarization method of geophysical exploration would measure an anomaly due to meteorite debris at the impact site at Meteor Crater, near Winslow, Arizona.

All work has been completed for this phase of the supported study. Results of the survey were favorable to the objectives. Mr. Joe Wilkins is using the results of this project for his Master's degree at the University.

Publications:

A paper concerning this project was given at the meeting of the American Geophysical Union in Washington, D.C., April 7-11, 1968.

Grant Number 4. June 15, 1966 $5,000

Principal Investigator Robert Lansing, Professor
Department of Psychology

Title: An Exploratory Investigation of Electroencephalographic Measures of Carbon Dioxide Sensitivity in Man

Summary:

The original purpose of this investigation was to determine the sensitivity of the higher nervous centers of the brain to carbon dioxide through measures of the brain's electrical activity as recorded from the scalp. In particular, we were interested in the relation of these EEG potentials to respiratory changes produced by rather simple techniques. The procedures and the results we have obtained are described below.

A. Breath-holding: We followed the standard physiological procedures for producing an elevation of blood CO_2 during voluntary breath-holding. Subjects took five breaths of 100% oxygen, then inhaled a standard volume and held their breath to the breaking point. During this period the background EEG activity was recorded from the occipital and central regions. Under these conditions the major occipital rhythm, the alpha rhythm, remained unchanged but there was a reduction in the 8 to 12 cps rhythms of the central region. In the first breath-holding trials a marked increase in muscle potentials and an activation of the EEG patterns occurred within a few seconds of the breaking point but this effect disappeared with repetition of the procedure. Since ear oximetry was carried out to assure that no hypoxia developed under these conditions, these effects are interpreted therefore as being due to an increased level of CO_2 in the blood.

B. Short-term Breathing of 5% Carbon Dioxide: This experiment was carried out with 8 normal young adults as part of a Master's thesis by Peter Crown, a

graduate student in Psychology. The Master's thesis has been completed and an abstract of that paper is included in this report. The most important find was that, again, the central region is significantly affected by increases of CO_2 which confirms previous studies with animals. These brain potential changes are closely associated with rise of CO_2 in the blood but follow a different time course than the increase in ventilation which results from breathing CO_2. It is clear, then, that Dell's hypothesis that there is an activation of higher centers, evidenced in the EEG, simultaneously with the activation of breathing response does not hold in man, under these conditions. Further, the effect on visual response of the brain evoked by stroboscopic flashes is quite variable from one subject to another and we were not able to confirm Grey Walter's finding of an increased amplitude of the late potentials.

C. Brief Pulses of Carbon Dioxide: In this experiment the subject breathed room air continually for two hours, but during this time at regular intervals he received four breaths of 11% carbon dioxide or four breaths of a control air mixture. These very brief exposures permit a transient increase in CO_2 very near the respiratory threshold and the blood increases in CO_2 are near to those which are produced in the normal pauses of breathing during conversation or eating, etc. The value of this method is that it permits an evaluation of EEG and breathing response independent of many physiological systems which may be brought into play with more prolonged exposure. This consistently produced an increase in ventilation for periods of a minute with no discernible change in the EEG patterns of either the central or the occipital region. In spite of detailed analysis of several frequency bands it is possible that a very subtle change in electrical activity might have occurred. We interpret our results to indicate again that under certain conditions ventilatory response controlled by the lower brain stem can occur independent of changes in the cerebral cortex at least insofar as EEG measures are concerned.

D. Rebreathing: This study was carried out by the principal investigator and Mr. Stuart Stoloff. Again, young normal volunteers were used as subjects. While EEG tracings were being obtained, subjects breathed in and out of a respirometer; for CO_2 increases the CO_2 absorber was removed from the breathing circuit without the subject's knowledge and for control runs the absorber remained in so that no increase in carbon dioxide would occur. There was a base line recording period and a three minute rebreathing period and then a five minute recovery period. During the rebreathing of carbon dioxide there was a slight but slowly increasing activity in the 8-12 cps range. There was a significant reduction of amplitude of activity in this frequency range during the course of both the control air and the CO_2 breathing periods. A suppression of alpha activity was significantly greater during the CO_2 rebreathing than the air control in the central region. The changes in activity of other frequency ranges and the relation of these to respiratory increases has not yet been completed. These findings will be reported when they are available.

Conclusions: In general increasing blood levels of CO_2 with the brief and simple procedures outlined above may produce marked ventilatory response without affecting gross appearance of the electrical recordings from the occipital and central regions. Visual analysis therefore of the type usually employed in discerning severe metabolic disturbances of brain function or of classifying various levels of sleep and wakefulness would be of little value in monitoring the brain's response to CO_2 even when respiration is markedly altered. The only consistent effects we have been able to determine have required detailed hand measurement of alpha frequency or automatic integration of selected frequency ranges. The central region appears to be most responsive to hypercapnia and we have interpreted our findings as indicating an activation or increased excitability of that region during CO_2 buildup. These changes observed in EEG recordings do not in general parallel increases in ventilation. They should therefore be regarded as somewhat different measures of central nervous system sensitivity to CO_2.

The EEG potentials obtained in most of the experiments above are permanently recorded on tape. During my sabbatical leave (August 1968-August 1969) in conjunction with my research at M.I.T. I subjected these recordings to more detailed computer analysis. They have previously applied these analyses to data they have recorded in rats during transient elevations of CO_2 and we are interested in comparing these. We plan no further work at this time in our laboratory along these lines but hope to return to it again in a year or so.

Publications:

The results of this study were presented in February 1968 to the Western Electroencephalographic Society at its annual meeting.

Grant Number 5. June 15, 1966 $1,670
(See also Grant Number 43)

Principal Investigator Lee B. Jones, Assistant Professor
Department of Chemistry

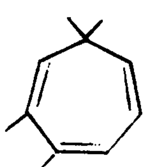
Title: The Mechanism of Photochemical Reactions

Summary:

The purpose of this research was to determine the effects of electromagnetic radiation (particularly in the ultraviolet region) on organic hydrocarbons. A further point of interest was the effect of substituents on the course of the reactions promoted by ultraviolet radiation.

As was demonstrated by the photolysis of 3,7,7-trimethylcycloheptatriene and 2,7,7-trimethylcycloheptatriene, the vinyl methyl group situated at either position 2 or 3 exerts a strong directive influence on the course of methyl migration and electrocyclization reactions. It was of interest, therefore, to compare the relative directive influences of the methyl groups at the 2 and 3 positions when present in the same molecule and so a study of the photolysis of (1) in benzene solution was initiated.

Photoisomerization of (1) proved to be extremely complex. Irradiation of a benzene solution of (1) to 75% reaction gives a mixture consisting of 45% of bicyclic compounds, 25% of unreacted (1), and 30% of new trienes.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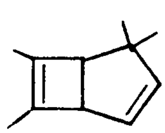
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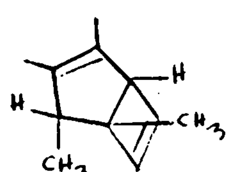
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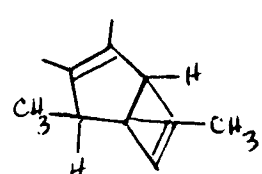
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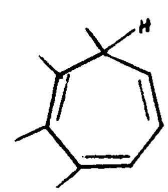
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The bicyclic products consist of seven peaks in the relative amounts of 10% (four peaks), 65% of (2), 15% of (3), and 10% of (4). The new trienes consist of two partially resolved peaks in the relative amounts of 25% and

75%. The two new trienes do not give clearcut NMR spectra and do not appear to be interconvertable under the photolysis conditions. Therefore, it would appear that these are mixtures of trienes which cannot be resolved under our analyzing conditions. The bicyclic (2) has been identified from NMR spectra. The structures of (3) and (4) have been assigned on the basis of deuterium labelling experiments and double irradiation experiments, and must arise from triene (5), which appears to be the preferable course of 1,7 methyl sigmatropic migration. Irradiation of the major new trienes peak gives (3) and (4) as the major bicyclics, in addition to other bicyclic compounds, which would support the hypothesis that (5) is the preferred new triene to be formed. This is in accord with molecular obital calculations described in publications resulting from earlier work on this problem.

Publications:

Jones, Lee B. and Jones, Vera K., J. Am. Chem. Soc., 89, 1880 (1967).

Jones, Lee B. and Jones, Vera K., ibid, 90, 1540 (1968).

Grant Number 6. September 15, 1966 $5,000
(Proposal approved in June, subject to alterations).

Principal Investigator Monte V. Davis, Professor
Department of Nuclear Engineering

Title: The Transport of Energy using Heat Pipes

Summary:

This research project has been completed. Final Report was included in the third Semi-Annual Report to NASA.

Grant Number 7. June 15, 1966 $5,000

Principal Investigator Morton E. Wacks, Associate Professor
Department of Nuclear Engineering

Title: Trace Element Analysis

Summary:

This work proposed a study of existing activation analysis techniques using thermal and fast neutron activation and an extension of these techniques by means of chemical separation, computer programming, and other improvements in an effort to lower existing detection limits. Comparisons were made with conventional chemical and instrumental techniques including that of absorption spectrum analysis.

Facilities were available for this work in the Nuclear Engineering Department and in the Department of Chemistry. Part of the research effort was directed toward the construction of a scintillation chamber which greatly increased our ability to detect high energy gamma rays.

In February 1967, Dr. Wacks attended the General Atomic Division of General Dynamics' course in Activation Analysis in San Diego, California. This was an essential part of the original proposal. As a result of this week's training, an improved computer program for analysis of complex gamma-ray spectra from multi-element activation has been written by a senior honors student, David Himes. In addition, a set of Royal-McBee Keysort cards has been prepared to help locate possible isotopes on the basis of the photo peak and half-life information.

The work performed by Mr. Himes became the topic of his senior honors thesis. This research was also presented as a paper at the Forty-third Annual

Meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science, held in Tucson, Arizona, April 29 through May 3, 1967.

It is felt that this grant has helped immensely in getting this research started and that an additional year's support at a reduced level would be beneficial to the development of an overall neutron activation capability for trace element analysis. This additional year's work would develop this capability for fast neutron activation using the Department of Nuclear Engineering's Van de Graaff generator. This extension would require an additional expenditure of $4,300.

Publications:

Abstract of paper presented at Forty-third Annual Meeting of the Southwestern and Rocky Mountain Division of the American Association for the Advancement of Science, Tucson, Arizona, April 29-May 3, 1967.

Grant Number 8. June 15, 1966 $5,000

Principal Investigator James L. Melsa, Assistant Professor
Department of Electrical Engineering

Title: Optimal and Sub-optimal Estimation Theory as Applied to Spacecraft Control and Guidance

Summary:

Fixed Configuration Optimization: Emphasis has been placed on extensions and improvements of the concept of specific optimal control. The use of a dynamical controller structure for the reduction of sensitivity in deterministic systems was investigated with promising results. A natural extension of the specific optimal controller is the specific optimal estimator - a fixed configuration estimator. The application of such an approach to linear and nonlinear filtering problems was examined with very satisfying results. The stochastic and adaptive problems were also treated by making combined and separate use of the above concepts.

Applications of Invariant Imbedding: Numerous facets of the application of invariant imbedding to control and estimation problems are being considered. The application of invariant imbedding to solve the combined stochastic control problem with greatly reduced computational requirements has been very successful. This procedure has also been applied to the stochastic differential control problems.

Optimal Control with Discontinuities: The optimal control problems with discontinuities in the state variables and/or their derivatives were investigated by means of Dynamic Programming. This approach eliminates the use of the corner conditions and may be used to handle state space constraints in a more convenient fashion than the classical approach. The application of this technique to the rocket-staging problem is now being investigated.

The Department of Electrical Engineering supported the effort by providing Dr. Melsa with one-quarter time for research and by providing free analog and digital computer facilities.

During 1968, two half-time graduate assistants, Mr. Craig Sims and Mr. William Bottorff, were supported by the grant. In addition, Dr. Donald Nordahl and Mr. Clyde McLennan, NASA fellowship holders, were engaged in research in the area of the grant under the direction of Dr. Melsa.

Mr. Sims and Mr. McLennan completed the Master's degree requirements using their research from this grant. Mr. Nordahl completed the PhD in September 1967.

Some research support was obtained from NASA for continued investigation of the research area of this grant. Another proposal has been submitted for additional support to broaden the scope of the research.

Publications:

Nordahl, D.M., and Nelson, J.L., "A New Approach to Stochastic Control", Proc. of Second Annual Princeton Conf. on Information Sciences and Systems, March 25-26, 1968.

Bottorff, W.W. and Melsa, J.L., "Optimal Non-Resetting Data Reconstruction", Proc. of the 1968 IEGG Region III Meeting, April 22-24, 1968, New Orleans, Louisiana.

Sims, C.S. and Melsa, J.L., "Sensitivity Reduction in Specific Optimal Control by the Use of a Dynamical Controller", to be published in the International Journal of Control.

Grant Number 9. June 15, 1966 $4,000

Principal Investigator Robert L. Waland, Research Associate
Lunar and Planetary Laboratory

Title: Partial Funding for Novel Telescope Design

Summary:

The project entails the development of a catadioptric optical system capable of yielding good images over an area of the sky approximately 20 square degrees. This instrument is composed of one spherical mirror and a thin nearly plane parallel plate placed at the center of curvature of the mirror. One surface of the plate is given a 4th power surface to annul the on and off-axis abberations of the system. This instrument is eminently suitable for cometary research and is being used by Dr. E. Roemer of the Lunar and Planetary Laboratory where she is considered an expert in that field.

The 27-inch diameter spherical mirror has been completed in the Laboratory Optical Shop. The 18-inch diameter plane parallel plate, with a working aperture of 16 inches, has been optically worked on one side to a near optically flat surface. The other side has been prepared to receive the 4th power surface. All design work and generation of optical surfaces have been carried out in our own Optical Shop, without any outside help.

Publications:

No publications are anticipated since the design of the optics has been adequately covered by I.S. Bowen and E.H. Linfoot and others.

Grant Number 10. June 15, 1966 $5,000

Principal Investigator L. J. Demer, Professor
Department of Metallurgical Engineering

Title: The Damping Characteristics of Engineering Materials

Summary:

This research project is concerned with application of a new method of analysis for the energy dissipative characteristics of materials under cyclic loading. It is expected to provide specific material constants which have not been available heretofore because of the limitations of the loading techniques employed and analytical methods utilized in prior damping tests of materials.

Progress is being made on further analytical development of the suggested new method of analysis, evaluating its abilities by use of an analog computer, and applying the technique to determination of the damping constants of a variety of materials over the stress range of engineering interest. It is expected that the results of the study will be of significant engineering importance.

Mr. Douglas Fancher completed the requirements for the M.S. degree in Metallurgy at the end of the fall semester (in January, 1968), having been concerned in his research with an investigation of an application of the rheological epicycle method of analysis to plain carbon steel and an aluminum alloy. He obtained stress-strain hysteresis loops for these materials and analyzed them by the above method. His results disclosed a high sensitivity of the parameters in the mathematical formulation to even slight variations in the form of the hysteresis loops as caused by variations in strain amplitude or changes in the number of cycles in the stress history. Furthermore, these parameters varied quite consistently with both cyclic-strain amplitude and number of cycles. It is planned to reduce the thesis to a form suitable for publication. This is being delayed somewhat because Mr. Fancher, instead of going on with a Ph.D. program as earlier intended, has left the University and accepted a position in industry. Lack of available support was one factor in his decision, though not the only consideration.

Mr. John Decker, another graduate student in the Department, adopted as his Master's thesis investigation a more idealized evaluation of the newly proposed epicyclic method of damping analysis, by study of the response of various idealized models to various standard inputs and then obtaining the response behavior by analytical methods or by use of a PACE-231-R Analog Computer. This work is progressing slowly because Mr. Decker, for lack of support, left the University in the fall of 1967 to work in industry. His plan to carry his study to the point of completing the thesis requirements for the M.S. degree in Metallurgical Engineering is being carried out at a rather slow pace due to his infrequent periodic visits to the University to use the computer. His experimental work is thus, perhaps, 50% completed.

Another Master's candidate, Mr. Andrew Chaloka, has been doing a research investigation in the general area of the grant. His plans are to follow Mr. Fancher in studying real materials; however, Mr. Chaloka plans to study the behavior of a material such as Type 403 stainless, whose magneto-elastic damping behavior has already been investigated in other studies but which offers an appropriate behavior for analysis by the rheological epicycle method. The Carpenter Steel Company has donated specimen material both of Type 403 and Type Custom 455 Steel, a newly developed alloy of attractive super-plastic behavior, both of which demonstrate appreciable damping of the magneto-elastic type. Mr. Chaloka will soon be obtaining experimental data for analysis and hopes to complete the requirements for his degree by the end of the summer of 1968. He is being supported by a Departmental assistantship during the academic year.

Another graduate student in the Metallurgical Engineering Department, Mr. Ernest Honig, completed the requirements for his M.S. degree in April 1967 and is now initiating a doctoral research program in the grant area as the research problem for his dissertation. He plans to extend the epicyclic analytical method to obtain a comparison of the Fourier Series analysis with the Laurent Series representation of the generalized hysteresis behavior of real materials. It is proposed that the latter representation will overcome uniqueness problems obtained from standard tests run on a material that will enable preperiodic input function waveform. It is also proposed by Mr. Honig to make a correlation between the descriptive parameters of a system and the primary mechanisms responsible for energy dissipation in the material so that the primary dissipation mechanisms can be recognized from material response curves.

The above three aspects, namely, development of descriptive parameters for the behavior of a material under periodic inputs, the prediction of response to a whole variety of periodic inputs, and the possibility of recognition of dissipation mechanisms from response to periodic excitation are topics of important engineering value. Success in these areas will be a significant engineering contribution.

Mr. Honig has applied for scholarship support from NSF and NASA Fellowship programs, and in the event that he is unsuccessful with these, he will rely on a departmental assistantship for support.

Lack of sufficient support whereby students can devote their efforts to research is hampering the general conduct of this investigation. However, until the international situation eases and more money is channeled into the support of basic research, it is doubtful if the present situation will be altered. In the meantime, we can only rely on the small amount of remaining grant funds for equipment and supplies to keep the study moving.

Grant Number 11. June 15, 1966 $10,000

Principal Investigator Granino A. Korn, Professor
Department of Electrical Engineering

Title: Analog-Hybrid Computer Laboratory

Summary:

Development of High-speed D/A Multipliers (O'Grady): Two electronic switches suitable for 12-bit multiplying D/A converters were designed and tested; one is a MOSFET series switch combined with a low-leakage silicon-transistor shunt switch, and the other is a double bipolar-transistor shunt switch. Tests showed that the latter type of switch produced smaller temperature-drift errors, so that this design was adopted for the ASTRAC II/PDP-9 analog-digital computer linkage. The entire ASTRAC II/PDP-9 linkage, comprising four multiplying A/D converters, is now completed and has been calibrated and tested; a complete report on the design of the new digital-to-analog converters formed a part of Mr. O'Grady's Ph.D. thesis, which was completed in June 1968.

Other Applications of D/A Switches (O'Grady, Conant, Hartmann): The improved D/A switches developed for the D/A converters proved useful for several other applications in our ASTRAC II and LOCUST iterative differential analyzers, in particular:

1. Four-channel multiplexers for the ASTRAC II/PDP-9 linkage analog-to-digital computer.

2. A four-channel oscilloscope multiplexer for oscilloscope readout from the ASTRAC II computer.

3. General-purpose D/A switches (for automatic programming) in the LOCUST computer.

4. Ladder-network D/A multipliers as coefficient setting attenuators (Pracht).

Mr. Pracht's M.S. thesis, one-half of which was supported by the subject grant, was successfully completed and published in SIMULATION. This project investigated the use of read-relay multipliers to replace servo-set potentiometers in hybrid/analog/digital computers. We believe our system constitutes a substantial improvement over existing art, as regards setting speed and system cost.

Digital-computer Display-console Development (Simons): Two digital-to-analog converters were expanded to nine-bit capacity with the new shunt switches and were combined with a set of commercially available digital-logic cards and an existing large-screen display oscilloscope into a graphical display console for the PDP-9 digital computer. This project which was about one-third supported by the subject grant, has, we think, led to a particularly interesting combination of hardware and software techniques. A single 18-bit PDP-9 word is used to provide two nine-bit x and y words for positioning the cathode-ray-tube beam, thus saving one-half the memory required to store or refresh graphic displays and to cut the flicker rate; switchable capacitors on the x and y amplifiers charge when the x and y voltages are incremented, thus providing very inexpensive vector generation or interpolation between curve points (similar to the MIT PHASE PLOT system); and the x register can be incremented at various rates for curve-plotting without any need for computer readout of x voltages.

Study of Data Reconstruction for Displays and for Hybrid Computation. (Wait, Ames, Burkhardt):

This study involved the review of theoretical error estimates and a set of ASTRAC II experiments. The report discusses and tabulates both maximum and mean-square errors for zero order, fractional order, first order, and polygonal hold circuits used in digital-to-analog conversion.

Relation to our other research activities: The development work supported by the subject institutional grant has not only produced very valuable educational and research experience for our graduate students, but has also produced hardware which will be permanently useful in our other research activities. This has proved to be particularly important in our engineering laboratory, since especially NSF grants are mainly graduate-education oriented and expect the institution to supply much of the needed hardware. As a case in point, the newly developed digital-to-analog converters and switches have taken their places in the completed ASTRAC II/PDP-9 analog-digital linkage, and this project is now supported by an extension of NASA Grant NSG-646, which again deals mainly with hybrid-computer applications. The new digital-computer display-console development, whose non-hardware support has now been taken over by our new NSF-funded digital simulation study, is a completely vital part of the latter research project, since it will plot differential-equation solutions in the course of the simulation.

Publications:

Pracht, C. "A New Digital-attenuator System for Hybrid Computers", SIMULATION, April, 1967.

O'Grady, E.O. "Design and Application of an Analog-Hybrid-Digital Computer Linkage", Ph. D. Thesis (submitted in June 1968).

Simons, S. "A Graphical Display for the PDP-9", M.S. thesis (submitted in June 1968).

Wait, J.V. "Data Reconstruction Errors: Fractional and Polygonal Holds", ACL Memo No. 140, University of Arizona, Dept. of Electrical Engineering, July 1967.

Grant Number 12. November 1, 1967 $5,000
(See also Grant Number 39)

Investigator Cecil Rogers, Assistant Professor
Department of Psychology

Title: Skilled Motor Responses

Summary:

See Report for Grant Number 39.

Grant Number 13. June 15, 1966 $5,000

Investigator S. F. Jacobs, Professor
Optical Sciences

Title: The Limitations of Coherent Optical Detection

Summary:

This research project has been completed. Final Report was included in the second Semiannual Report.

Grant Number 14. June 15, 1966 $5,000

Investigator George Tyras, Associate Professor
Department of Electrical Engineering

Title: Study of Propagation, Diffraction and Coherence of Bounded Beams

Summary:

This research project has been completed. A final report was included with the third Semiannual Report.

Grant Number 15. June 15, 1966 $6,000

Investigator Frank Low, Professor
Lunar and Planetary Laboratory

Title: Air-borne Infrared Astronomy

Summary:

The research work on this grant has been completed. Final Report was included in the second Semiannual Report.

Grant Number 16. June 15, 1966 $1,000

Investigator Ewen A. Whitaker, Research Associate
Lunar and Planetary Laboratory

Title: Lunar Surface Photography

Summary:

The objective of this project is to obtain photographs of the lunar surface in which the differences in reflectivity of that surface are eliminated, but the small differences in color are strongly enhanced. Since differences in color are largely, if not totally, indicative of chemical differences, this technique is a powerful tool for the geological study of the moon. Feasibility studies made prior to the award of this grant demonstrated the practicability of the technique, and proved the essential correctness of the flow theory of the lunar maria as against the dust migration theory (T. Gold).

Since the last report, the camera has been equipped with a simple detachable mechanical speed governor, and the densitometer has been accurately calibrated. Observing time with the 61-inch reflector was obtained for the nights March 12, 13, 14 and April 11 and 12, 1968; the latter two nights were clouded out, but the former three were clear. Trial exposures for the five filters were made on the first night, including the sensitometric wedge. On the following nights, 58 plates were secured; these appear to be of good quality in view of the somewhat mediocre seeing conditions.

Subsequent densitometer measurements show that the exposures lie within the straight line portion of the photographic gamma curve (a necessary condition). The next step of producing gamma-controlled positive will be undertaken as soon as sufficient darkroom time becomes available.

No publications have been made so far, neither has outside support been required. No graduate students have participated in this program. It is anticipated that an LPL Communication will eventually be published containing a series of 12 photographs resulting from the work under this grant.

Grant Number 17. June 15, 1966 $4,500

Investigators Dale Cruikshank and Alan Binder, graduate students under Dr. G. P. Kuiper
Lunar and Planetary Laboratory

Title: Electronics for a 10-channel Spectrometer for Infrared Planetary Spectrophotometry

Summary:

The 10-channel spectrometer was devised to obtain simultaneous sampling of the infrared spectrum (0.8 to 2.8 microns) of the planets, satellites, moon and stars. The grant discussed here provided funds for development of the electronics required in this work.

During the last six months it became clear that considerable additional funding would be required for the continued development of the 10-channel spectrometer and its electronics complement. Co-investigator Binder has since relocated at the IIT Research Institute, Chicago, Illinois, and has obtained in-house funding from the Institute for this work. Accordingly, all optical and some electronic components of the 10-channel instrument have been transferred, on a loan basis, to the IIT Research Institute for continued development. Binder now becomes the principal investigator on this project, which is receiving his full-time efforts and funding in the amount of approximately $30,000.

Because of the funds received through the NASA Institutional Grant have been of great importance to the development of this instrumentation, it is expected to provide the Space Science Committee with the required reprints of scientific results when they become available. It is intended to use the spectrometer, when completed, with the 61-inch telescope of the Lunar and Planetary Laboratory jointly with Binder, Cruikshank, and other LPL personnel.

The Space Sciences Committee may regard this as the final report on the Institutional Grant for the 10-channel Spectrometer Electronics. The investigators would like to close by thanking the Committee for its consideration in providing funds for the development of an instrument which, when fully operational, should provide valuable new information on the infrared spectra of the planets, satellites, stars, and small areas on the moon.

Grant Number 18. June 15, 1966 $6,000

Investigator Donald J. Taylor, Assistant Professor
Department of Astronomy

Title: Far Ultraviolet Filtering for Space Optical Systems

Summary:

This research project is concerned with two types of interference filters for the ultraviolet portion of the spectrum: broad-band reflection filters and transmission filters with a narrower passband. These may prove quite useful in space optical systems. The emphasis for this project is on design methods, using metals and a dielectric material, and the feasibility of making such devices.

The final report on this grant is attached.

RESEARCH IN FAR ULTRAVIOLET FILTERING
FOR SPACE OPTICAL SYSTEMS

Partially Supported by NASA Grant NGR 03-002-032,
NASA Contract NAS 8-20651 and NASA Grant NGR 03-002-091

D. J. TAYLOR
Principal Investigator

D. B. McKENNEY
Coinvestigator

W. G. TIFFT
Coinvestigator

SPACE ASTRONOMY
of the
STEWARD OBSERVATORY

UNIVERSITY OF ARIZONA
TUCSON, ARIZONA

April 1, 1969

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INTRODUCTION

This program was initiated to investigate the design and fabrication of multilayer interference filters for the far ultraviolet. The research has been supported, in part, by NASA institutional grant NGR-03-002-091 beginning in June 1966. This document constitutes the final technical report for that grant. Most of the equipment utilized was derived through NASA contract NAS8-20651, grant NSG-732, and general funds within the Optical Sciences Center.

The main impetus for this program has been provided by a need for both reflection and transmission filters to be used in an ultraviolet sky survey camera which is being developed under NASA contract NAS8-20651 and grant NSG-732 to record ultraviolet light from stellar and nebular objects in the region from 140 nm to 300 nm. The most important filters for this project are reflection filters, which will be applied to the three mirrors of the camera. For highest system efficiency, the mirrors must be highly reflective in a moderately narrow region in the ultraviolet and have low reflectance at longer wavelengths. Such mirrors are generally referred to as "solar-blind" mirrors. Ultraviolet transmission filters are also required; these will be discussed briefly.

This report contains five sections following this introduction. First, computed theoretical properties of two types of reflection filters are presented, and a systematic design method is discussed. Second, problems associated with the vacuum system in which the filters are made are considered. The most critical part of producing interference filters is the control of the thickness of the filter layers. The optical monitor system developed for this work is described (third section), and the results are summarized (fourth section). In the final section, recommendations for further work are given.

THEORETICAL PROPERTIES OF ULTRAVIOLET FILTERS

The problem of designing and producing interference filters for the ultraviolet is basically the same as for any other region of the spectrum except that one is severely limited in the choice of materials with suitable optical properties. There are very few materials that are transparent in the ultraviolet. Rather than searching for "new" materials, we have limited ourselves to three materials: aluminum, chromium, and magnesium fluoride, which have a long history of use down to wavelengths as short as 120 nm.

Method of calculation

For purposes of calculation, we define an interference filter as an ordered series of plane parallel interfaces between media of different thicknesses and refractive indices, which is bounded by two semi-infinite media. Incident light is assumed to propagate from the medium of incidence toward the substrate medium. It is assumed that all layers are homogeneous and isotropic and hence can be characterized by a thickness and refractive index. As a result, we assume that there is a discontinuous change in the refractive index across a boundary. Previous experience indicates that this is a valid approximation.

Optical properties (reflectance, transmittance, and phase change on reflection) are calculated in a straightforward manner using a recursion relation which is a solution of Maxwell's equations with appropriate boundary conditions. The theory has previously been described by Berning.[1] The method used is called an admittance method. The essential parts of the calculation are described by Berning's Eqs. 151-156.

The computations were initially programmed for the IBM 7072 and, more recently, for the CDC 6400 computer in a program called THRUSH developed by the Optical Sciences Center of the University of Arizona. This is a general program which will compute the optical properties of any multilayer interference filter containing either metal or dielectric layers or a combination of them. The program can compute optical properties for discrete values of a variety of variables and will compute refractive indices of layers from dispersion data if needed. Fig. 1 is a block diagram of the basic program organization.

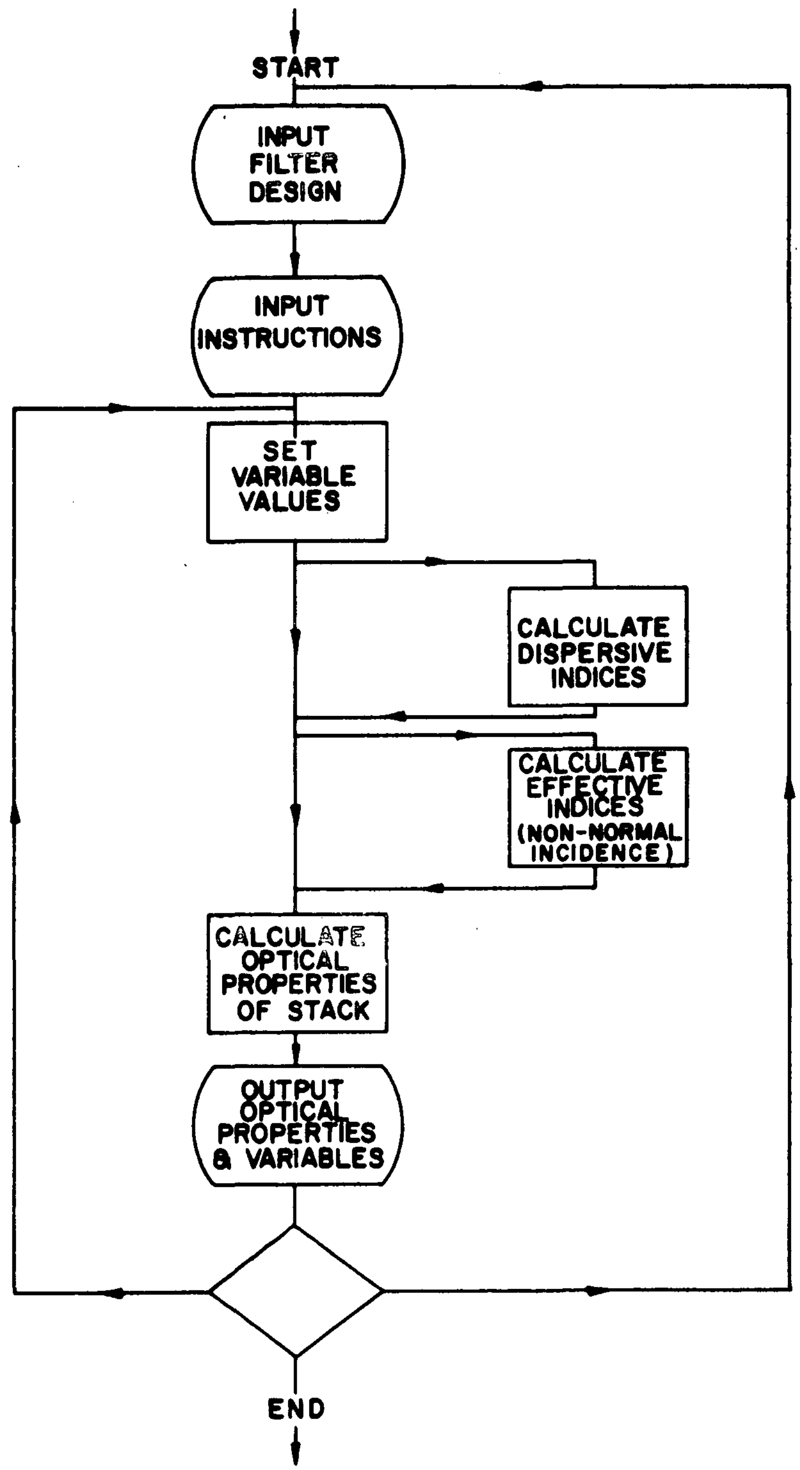

Fig. 1. Block diagram for THRUSH.

Computed properties of the mirror reflection filter

The simplest form of reflection filter is a mirror with an interference coating over it. We refer to this as a mirror reflection filter (MRF). A convenient form has been considered previously. It consists of a metal mirror coating with a dielectric layer and semitransparent metal layer over it. This configuration was considered by Hadley and Dennison.[2,3] They observed that there would be maxima and minima in the reflectance at wavelengths where the thickness of the dielectric layer was an even or odd multiple of a quarter wave.

The reflectance at a minimum depends on the thickness of the semitransparent metal layer. They considered the infrared region of the spectrum where they could make the approximation that the real and imaginary parts of the complex refractive index were approximately equal. They found it convenient to relate the thickness to the electrical resistance of the film such that, for a square film of thickness h and sides ℓ, the film resistance is inversely proportional to the thickness. For a resistance of 377 Ω (a thickness of 377 Ω/□), they computed and produced reflection filters with zero reflection minima. These investigations were extended into the visible spectrum by Turner[4] using aluminum and magnesium fluoride. He was able to produce filters in the visible with peak reflectances of 0.90 and minima near 0. The form of the spectral reflectance, which was observed experimentally, was a number of fairly broad minimum reflection regions separated by narrow high reflection bands near the wavelengths where the dielectric film was a multiple of $\lambda/2$ optically thick. The shapes of the high reflection bands were symmetrical (somewhat like a Gaussian curve). Two problems arose in predicting the reflectance. First, the thickness of the semitransparent metal layer required for zero minumum reflection did not agree with experimental values, and second, the shapes of the computed curves were just the opposite of the measured curves (i.e., the reflection minima were narrow and the maxima were broad and asymmetrical). This same type of filter was also made in the near ultraviolet.[5] For these filters, Turner found that better stability was achieved when the semitransparent metal layer was changed from aluminum to inconel. The optical properties were essentially the same as all previous results.

Natawa[6] tried to resolve the discrepancy between the computed and measured results by changing the optical constants of the outer aluminum layer in such a way that the reflectance of the bulk material would be unchanged.

He found it necessary to change the indices from their normal value of N = 1.36 - 6.05 i to N = 8.0 - 12.0 i, a change that is hard to believe.

We also tried to resolve the differences between the well accepted theory and the experimental observations. Our approach assumes that the optical constants do not depend on the thickness of the metal film. This assumption is known to be invlaid when the films are very thin. We have tried to find the thickness for which a particular reflectance will be a minimum. A series of computations has been made for the MRF using the combination opaque Al, MgF_2, semitransparent Al. From these calculations we had hoped to find (1) the properties of such an idealized filter and (2) whether the optical constants of the semitransparent metal are similar to thick film constants.

The results of the first calculations were unexpected. On checking the theory and computer program for possible errors, we found immediately that it was necessary to compute optical constants of the metal layer as a function of wavelength. Figure 2 shows how dispersion affects the optical properties of an MRF; curve A includes the variation of index with wavelength, and curve B uses a constant index. This indicates how strongly the optical constants of the metals affect the properties of an interference filter. The optical constants of aluminum used for this and all subsequent computations are shown below; the values were obtained from the *American Institute of Physics Handbook*[7] (for the region 700 - 220 nm) and from Hunter[8] (200 - 100 nm).

Optical constants of evaporated aluminum

λ(nm)	n	k
100	0.051	0.65
120	0.058	1.00
140	0.070	1.30
160	0.084	1.60
180	0.10	1.90
200	0.12	2.10
220	0.14	2.35
240	0.16	2.60
260	0.19	2.85
280	0.22	3.13
300	0.25	3.33
320	0.28	2.56
340	0.31	3.80
360	0.34	4.01
380	0.37	4.25
400	0.40	4.45
436	0.47	4.84
450	0.51	5.00
492	0.64	5.50
546	0.82	5.99
578	0.93	6.33
650	1.30	7.11
700	1.55	7.00

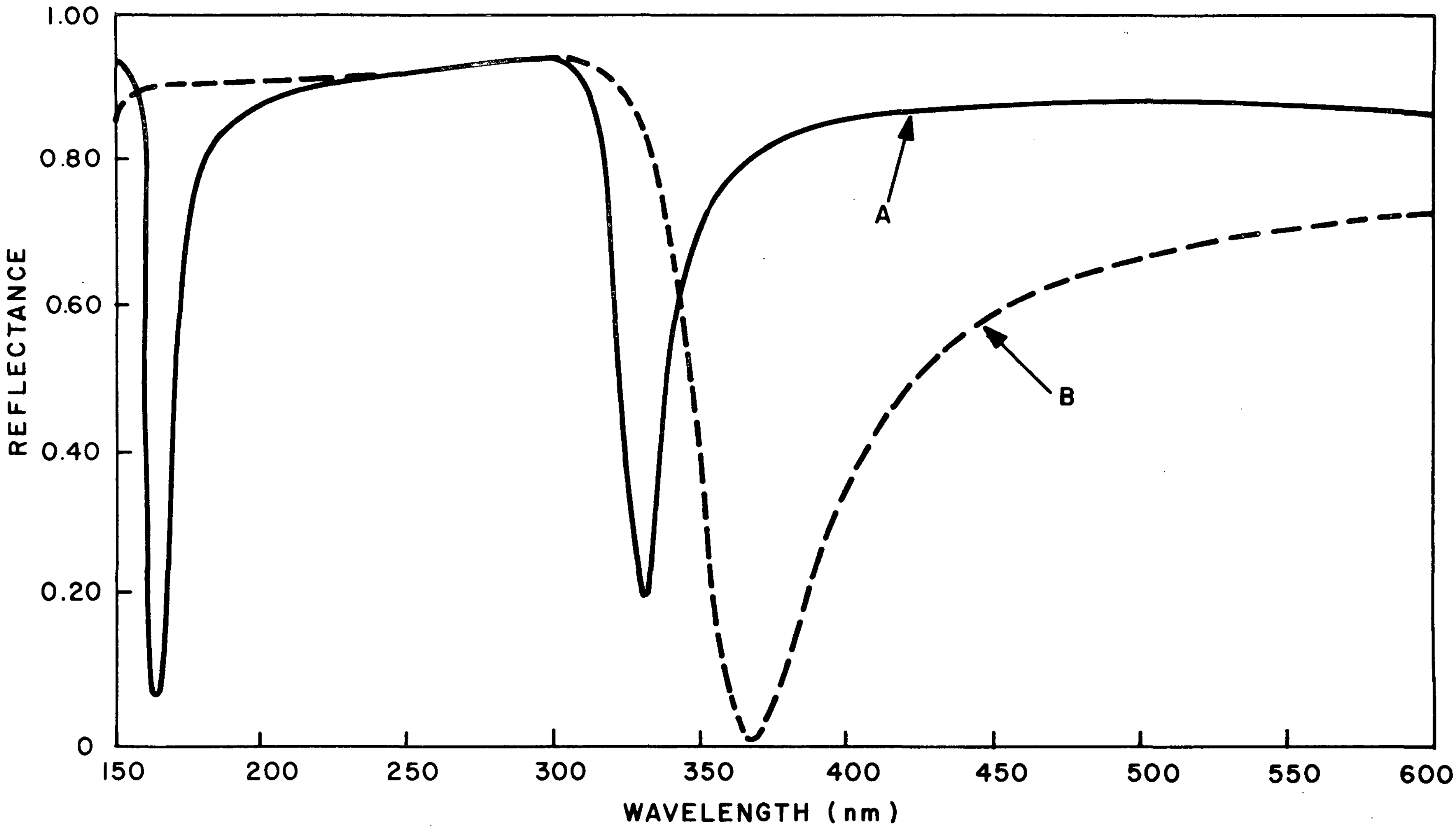

Fig. 2. The effect of the metal layer on the optical properties of a mirror reflection filter (MRF). (Curve A with dispersion, curve B without dispersion.)

Between data points the constants are computed from a modified form of the Sellmeyer equation:

$$n(\lambda) = A_n + \frac{B_n}{\lambda^2 + C_n} \tag{1}$$

$$k(\lambda) = A_k + \frac{B_k}{\lambda^2 + C_k} \tag{2}$$

where the constants A, B, and C are computed from the three closest values in the previous table. The values of the optical constants below 200 nm are extrapolated but are thought to be reasonably close since computed filter properties agree substantially with measurements.[9]

The properties of the mirror reflection filter can be described in a rather simple qualitative manner. There are two reflecting surfaces which are separated by a dielectric spacer layer. When the amplitudes of the waves reflected from the front and back surfaces are approximately equal, there will be a maximum reflectance when the waves are in phase and a minimum when they are out of phase. One could argue that a good approximation to the thickness for the semitransparent metal layer should be such that its reflectance is less than the reflectance of the opaque layer by a factor of T_1^2, where T_1 is the transmittance of the semitransparent metal layer. This value of the thickness depends on the wavelength of the minimum because of the dispersion of the optical constants, and this, in turn, depends on both the thickness of the metal and the thickness and index of the dielectric spacer layer. Thus, the design problem is no longer simple.

The properties of the mirror reflection filter consisting of opaque Al and MgF_2 and semitransparent Al are shown in Fig. 3 for a variety of metal thicknesses but constant dielectric spacer layer thickness. It is seen that a metal layer 10 nm thick gives a good minimum on the long wavelength side of the principal maximum, but the short wavelength minimum has not developed. A value of 20 nm seems to balance the two minima as seen in Fig. 2(curve A). It is apparently impossible to get the two minima to have zero reflectance simultaneously.

The shapes of these curves are in good agreement with earlier calculated results[4] but still disagree with experimental results. It can be argued that the computed results seem correct since they correspond to a Fabry-Perot or Fizeau interferometer in reflection where narrow dark fringes (corresponding to the narrow reflection minima) are observed against a bright background.

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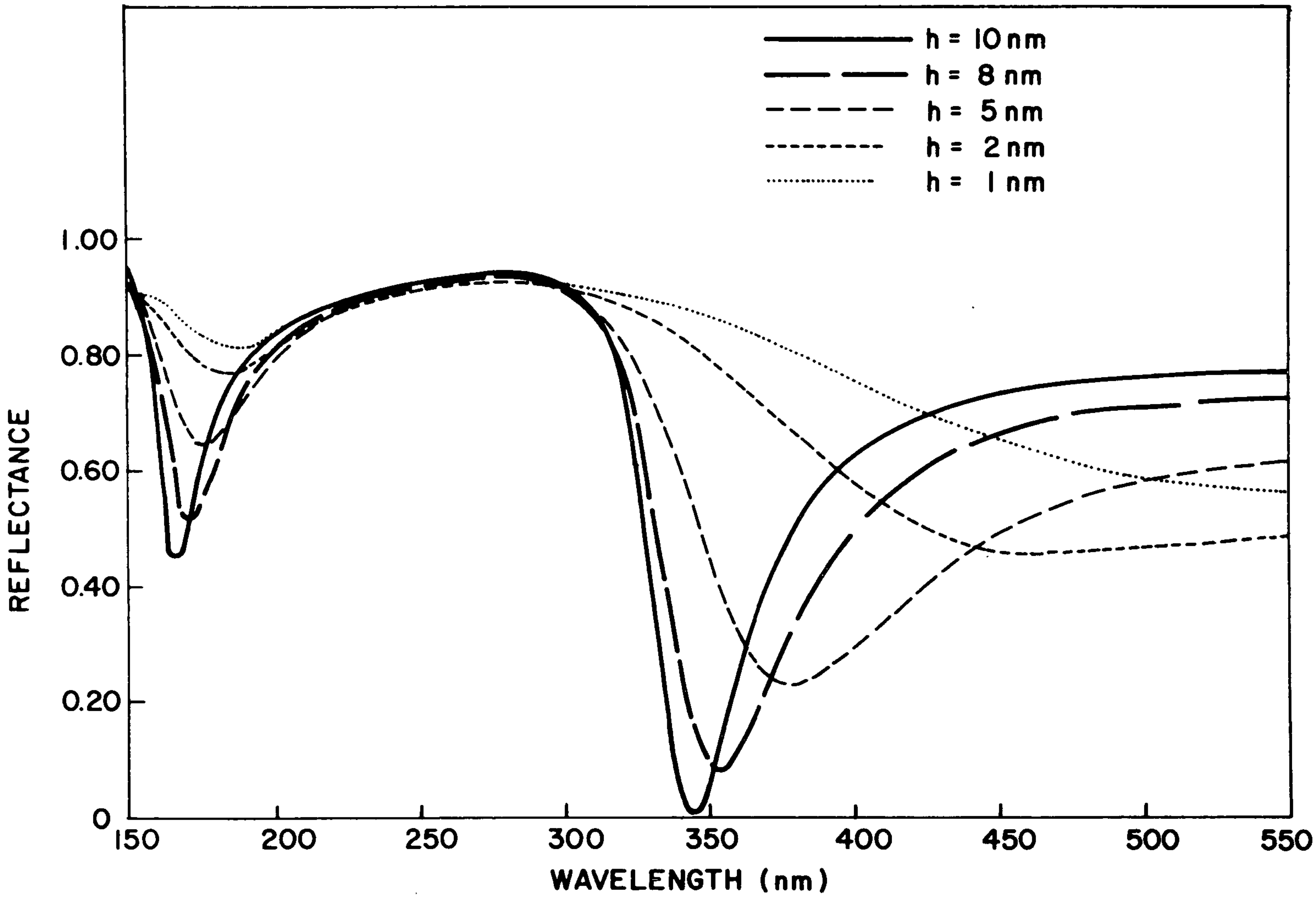


Fig. 3. Properties of a mirror reflection filter consisting of opaque Al, MgF_2, semitransparent Al, for different metal thicknesses.

For this same reason, we can argue that broader minima could be produced by using a semitransparent metal layer which has a lower reflectance. Metals with a lower ratio of k:n (imaginary:real part of the complex index) have this property. The computed reflectance of an MRF with chromium instead of aluminum as the outer layer is shown in Fig. 4. The narrower, more symmetrical reflection peak provides a better filter for broadband ultraviolet applications, and the lower background reflectance at long wavelengths provides a better solar-blind mirror. This type of filter has not been extensively investigated theoretically since the optical constants of chromium films are not well known. We have used limited data and considerable interpolation to arrive at the curve. It does not represent an "optimum" design using these materials. It may be possible to adjust the thickness of the chromium layer to balance the reflection minima and still retain the high peak reflectance. The shape of the reflection curve in Fig. 4 corresponds more closely with Turner's experimental results than when aluminum is used as the semitransparent film. The optical properties of chromium and inconel which Turner[5] used are similar. It is therefore reasonable to assume that the aluminum semitransparent films used by Turner were contaminated with aluminum oxide, which is known to increase the absorptance of aluminum. Experimental results discussed later support this assumption.

No simple means of designing MRF's has been found. In any iterative approach, the greatest amount of time is spent in finding the proper metal thickness, and it is necessary to do the computations as a function of the wavelength as previously discussed. As shown in Fig. 3, there is always a zero minimum, but its location for a given thickness of the dielectric layer would be difficult to predict without preliminary computations.

From our calculation, we conclude that a good solar-blind mirror cannot be made from three-layer combinations of aluminum and magnesium fluoride if the optical constants of aluminum are valid. The minimum is too narrow and reflectivity rises too rapidly again in the visible. It is obvious from older experimental results that there are certain conditions under which improved solar-blind properties do exist, but they are dependent upon such things as partial oxidation of the metal layers or impurities, and determining the best conditions would be a long task and would be difficult to reproduce using different coating apparatus. A more feasible approach seems

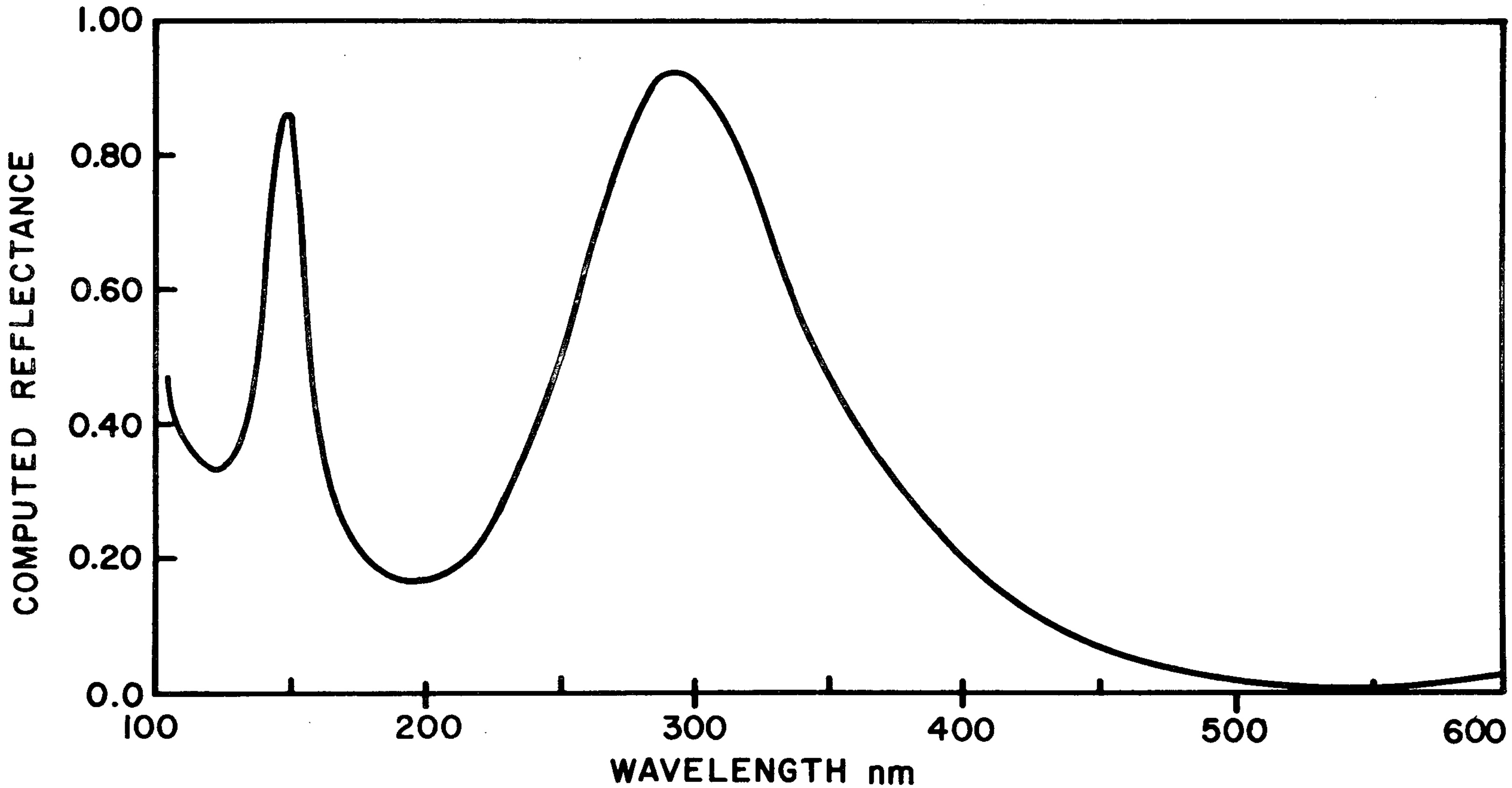


Fig. 4. The computed reflectance of a mirror reflection filter with chromium instead of aluminum as the outer layer.

to be that already pursued by Turner.[5] Either chromium or inconel will produce good three-layer solar-blind mirrors that would be durable and relatively simple to make.

One further point can be derived from the theoretical work. When monitoring the thickness of the metal layers during deposition, it is best to monitor each layer separately, in an attempt to get each layer as close to the optimum as possible. Finding the proper metal layer thickness for the semitransparent layer would otherwise be extremely difficult since a minimum reflectance is not necessarily the best thickness if there is a slight error in the dielectric thickness.

Computed properties of reflection filters with many layers

The spectral resolving power of the relatively simple filters discussed above is poor. The resolving power of any interferometer or interference phenomenon is increased as the number of coherent amplitude contributions is increased. Turner[5] demonstrated this by adding more transparent dielectric: semitransparent metal layer combinations to the three-layer mirror reflection filter. Using an empirical approach to find proper thicknesses, Turner found some good combinations. In this research, we have attempted to better understand the properties of these filters from theory to reduce the number of coating trials required and to try to find the optimum filter for a particular job.

We have begun by investigating what we call DMD stacks. The D stands for a dielectric layer which is one quarter wave optically thick and the M represents a metal layer. The three layers DMD represent a single symmetrical period, and the period may be repeated as $(DMD)^p$ or DMDDMDDM...MD. This class of filters has been found to have some interesting properties.

A series of calculations were carried out for DMD stacks in which both the number of periods p and the thickness of the metal h_M were changed, always keeping the dielectric layer thickness constant (250 nm quarter wave optical thickness). The results are shown in Figs. 5 and 6. We have plotted the reflectance and 1-transmittance. This procedure shows the absorptance as well since it must account for the gap between the two points. In Fig. 5, the number of periods p is varied. It can be seen that a relatively broad high reflection band is formed in the neighborhood of 250 nm and that the band becomes sharper and approaches a limiting width as the number of periods is increased. The thickness of the metal layers is changed in Fig. 6

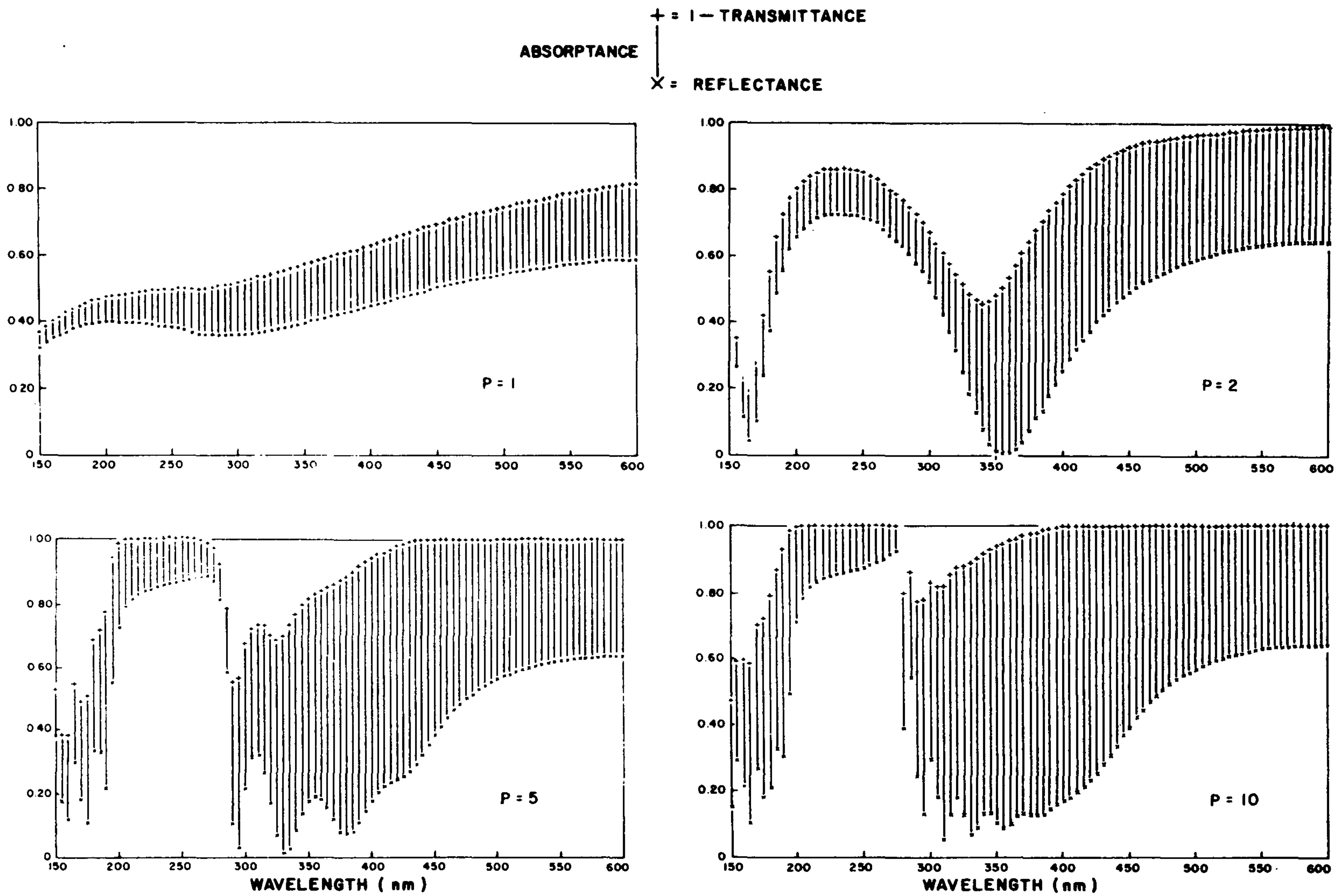


Fig. 5. DMD stacks with varied periods "p."

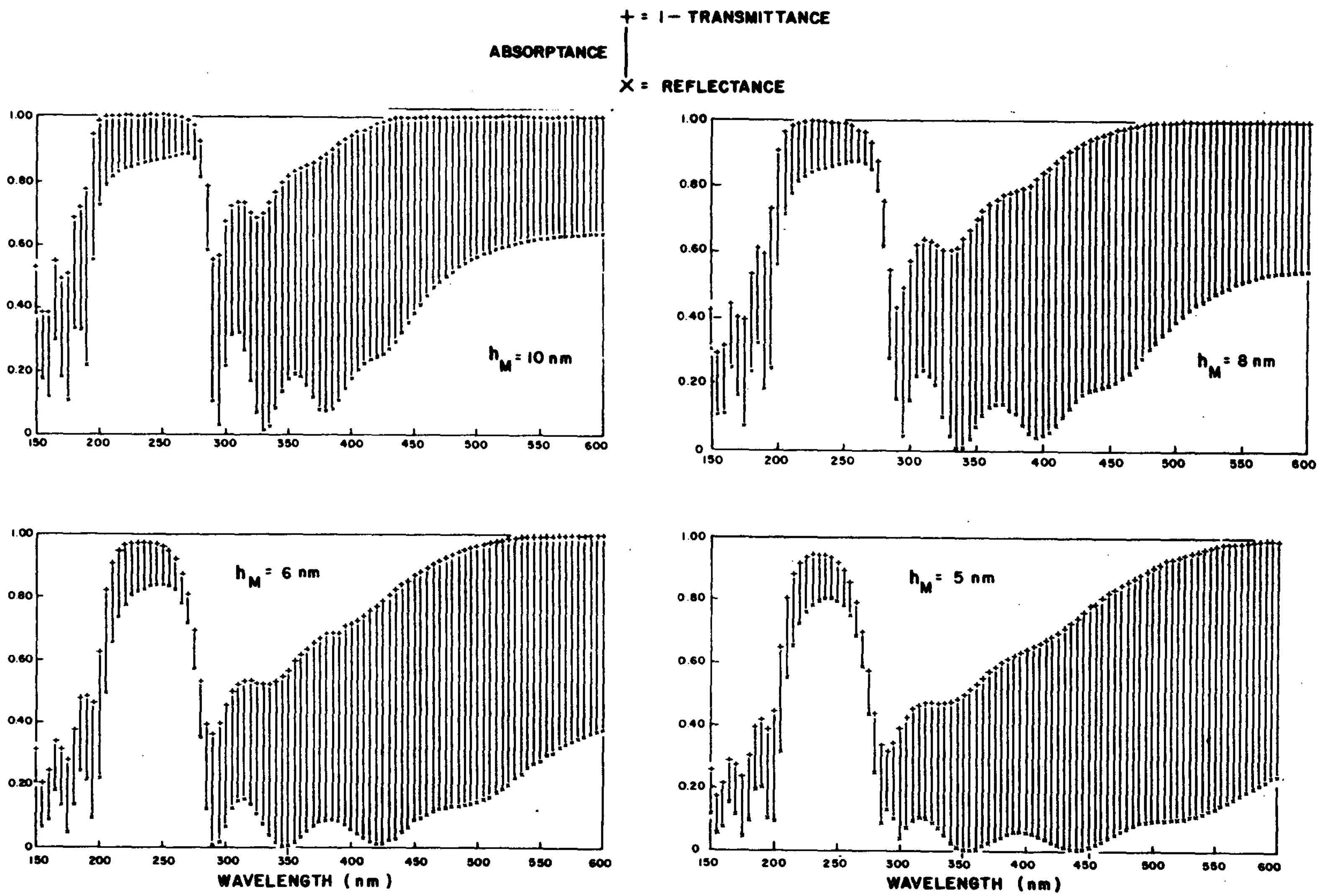


Fig. 6. DMD stacks with varied metal layer thicknesses, h_M.

for 5-period stacks. Two changes in the form of reflectance can be noted. Both the width of the high reflection band and the background reflection at longer wavelengths decrease with decreasing metal layer thickness. A good solar-blind mirror could be made with a metal thickness of ∿4.3 nm and 8 or more periods, according to our computations. The changing properties for thin metal layers may prohibit optimum filters of this type from being fully realized experimentally, however.

Some observations regarding the form of the spectral reflectance curves in Figs. 5 and 6 can be made which lend some insight into the properties of metal-dielectric interference filters without invoking detailed mathematics. First, we note that when dielectric films are $\lambda/2$ optically thick, they act just as though they were not there. When two or more DMD periods are joined, the films separating the metal layers will be $\lambda/2$ thick at 250 nm in the above examples. The reflectance and transmittance at this wavelength is thus just that of a single-period DMD stack with the appropriate metal thickness. In this case, we can imagine that the strength of the electromagnetic field, viewed as a standing wave, arrives at the next metal surface just as it left the preceding one, except with opposite sign. When the nodes in the electric field are at the metal surfaces, these surfaces will offer a minimum resistance, and the wave will pass on, giving a transmission maximum. With metal films, the phase change at metal-dielectric interfaces is important since we add amplitude with phases. The phase change on reflection for the interface between two dielectric media of different refractive indices is always 180°. The phase change on reflection from the boundary between a metal and a dielectric is always less than 180°. The phase change is dependent on the two refractive indices. This phase change causes the dielectric layers which separate two thin metal layers to act as if they were thicker than they actually are. Thus, for a given dielectric thickness, the standing wave pattern will be shifted to longer wavelengths. This can be shown in Fig. 5b, where the first transmission maximum is associated with a standing wave pattern which is of the lowest order ($\lambda/2$ optically thick). The peak is shifted from the normal half wave position at 250 nm to approximately 340 nm.

The positions of the antinodes are associated with the effective quarter wave optical thicknesses (odd multiples) of the dielectric layers. With an antinode condition, one generally expects to have a high reflectance and low transmittance. For the combination of materials shown in Fig. 5, these positions are at about 600 nm and 215 nm. For the relatively thick metal layers, there is a high reflectance. Where the thicknesses of the layers are actually $\lambda/2$ thick (250 nm) the reflectance is also high because films which are $\lambda/2$ thick act as if they were absent, and hence the reflectance is the same as for a thick metal film. The region between the actual $\lambda/2$ thickness and the effective quarter wave thickness determines the width of the high reflection band. The reflectance at the one-quarter and three-quarter wave positions is slightly different because of the difference in the optical constants and ratio of thickness to wavelength at these two wavelengths. By decreasing the thickness of the metal layers, we decrease the reflectance and increase the absorptance for each layer, giving the lower long wavelength reflectance and a narrower high reflectance band shown in Fig. 6.

From Fig. 5, it can be seen that one cannot further decrease long wavelength reflectance by adding more layers. The transmittance is very low at long wavelengths, so more layers of the same type will have little or no effect. As a general rule one should think of adding layers on the side of *emergence* where they can have an effect only when there is a transmission "window" to provide light with which to work.

A parallel between the high reflection band of the DMD stack and that of an all-dielectric stack can be drawn. Two DMD stacks separated by a spacer layer form the equivalent of an all-dielectric Fabry-Perot filter. The computed properties of such a filter are shown in Fig. 7 where, again, only aluminum and magnesium fluoride layers have been used. Although the transmission "leaks" look objectionable, such a filter used in conjunction with reflection filters of the type shown in Figs. 5 and 6 would be useful in isolating narrower spectral regions than would be possible with a reflection filter alone.

In conclusion, the DMD stack shows promise as a basis for ultraviolet filtering where a wide range of materials is unavailable. It is, theoretically, possible to control the reflectance in the ultraviolet as well as at longer wavelengths, making solar-blind mirrors possible. The greatest problem in realizing such filters experimentally is obtaining very thin metal films with good optical properties.

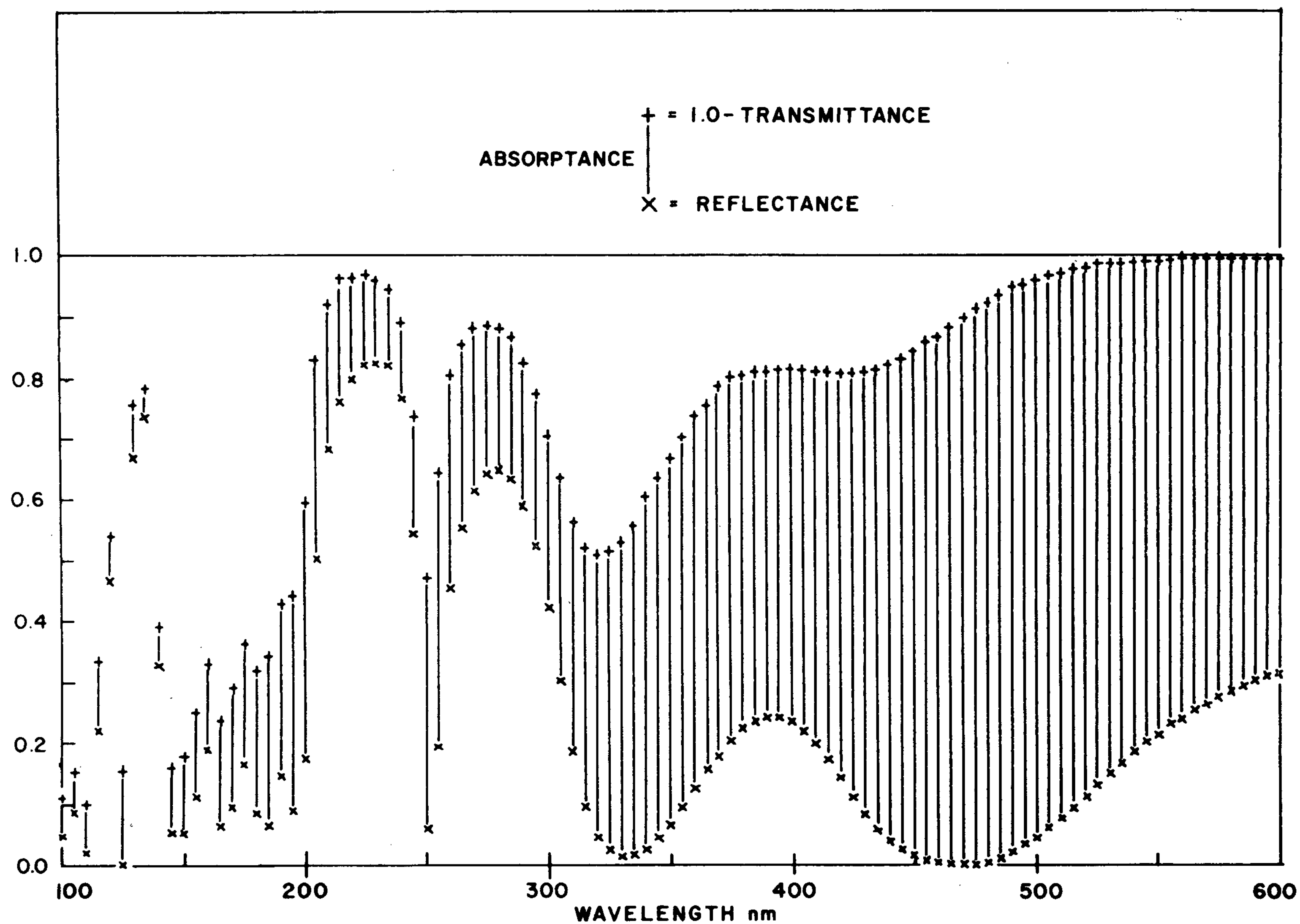


Fig. 7. Computed properties of a $(DMD)^3$ spacer $(DMD)^3$ Fabry-Perot filter.

THE VACUUM SYSTEM

General considerations

Most thin film interference filters have been made by vacuum evaporation. Chemical coating and vacuum sputtering can also be considered. In general, however, it is felt that evaporation is preferable because of higher film purity, more precise control of the thicknesses of the films, and better reproduceability. Simply stated, the evaporant (a solid) is heated in vacuum to form a vapor. The vapor strikes a cool surface (the substrate), and, under the proper conditions, most of the vapor sticks and forms a thin, uniform solid layer--a thin film. The essential parts of a vacuum *coater* are a means of producing a vacuum, a way of heating the evaporant, and, if the thickness of the film is important, a means of monitoring the thickness during deposition.

One of the early reasons for evaporating in vacuum was to allow the vapor to reach the substrate without hitting too many air molecules along the way. For some types of coatings, a vacuum is undesirable (for example, tin oxide coatings are prepared by evaporating stannous chloride in air.) Aluminum, however, is an active substance, especially in the molten or vapor state. To obtain "pure" aluminum coatings, the evaporation must be performed under pure conditions. Considerable work has been done to determine the best way of preparing aluminum films.[10] The current thinking is that the films should be evaporated in vacuum where the pressure is less than 10^{-5} torr and at high rates onto a cool (room temperature) substrate. The rate of evaporation is supposed to be greater than 60 nm/sec.

At such high rates, thickness control becomes a serious problem. There are basically three ways of controlling the thickness. First, one can preweigh the evaporant and evaporate all that there is. The accuracy using this technique is usually poor, since, in a violent situation, there is likely to be splashing or inconsistant distribution at the source. Also, the rate of evaporation depends on the amount of material. The second possibility is to evaporate at a predetermined rate for a certain period of time. This is inaccurate also since rate is difficult to control and the required mechanical shutters tend to be inaccurate. The third means is to monitor the thickness during evaporation. This, too, must rely on the accuracy of a mechanical shutter in addition (usually) to the uncertainty of human reaction time.

To get a feeling for the accuracies needed, consider that at the "minimum" rate of evaporation of 5-nm-thick film takes only 0.08 sec to evaporate, which for 10% accuracy would mean that the shutter would have to be better than ±8 ms. Considering that the shutter must work in vacuum, this seems nearly impossible to achieve.

We have reviewed the evaporation process to see if there might be some way to achieve the same results with a lower evaporation rate. Let us suppose that the aluminum vapor consists primarily of atoms and small molecules of aluminum which are mixed with some of the residual gas in proportion to the rate of evaporation. If the aluminum combines chemically with the residual gas, then the impure aluminum arriving at the substrate will be inversely proportional to the rate of evaporation. These contaminants will affect the entire film, as opposed to a surface contamination which occurs after the evaporation has stopped. On the basis of this argument, one should get the same results if the ratio of rate of evaporation to pressure during evaporation is constant, all other things being constant. This argument is valid over at least a few orders of magnitude and is the reason for going to an ultrahigh vacuum system for precise control of thin metal films.

The composition of residual gas in the vacuum system during and after evaporation will also have a large effect. One would not be concerned if residual gas were predominantly hydrogen or a rare inert gas, for example. Oxygen must be avoided as much as possible.

The ultrahigh vacuum system

For most of our evaporations, we have used an ultrahigh vacuum coater. Most of the system was built by Varian Associates and purchased under NASA contract NAS 8-20651. The system is completely free from oil pumps. The chamber is a cylinder 60 cm in diameter by 150 cm high. Rough pumping is accomplished with a gas aspirator pump in combination with cryogenic sorption pumps. The combination will pump the system to approximately 10^{-5} torr in 2 hours. The remainder of the pumping is accomplished by a 500 ℓ/sec sputter ion pump and cryogenic titanium sublimation pump rated at 10,000 ℓ/sec. Fig. 8 is a schematic diagram of the system. When the system is clean, it can be pumped to better than 5×10^{-11} torr in 24 hours. After two years of use without cleaning, the system can be pumped to 2×10^{-10} torr. The low pressures can be realized only after a prolonged bake-out at about 250°C.

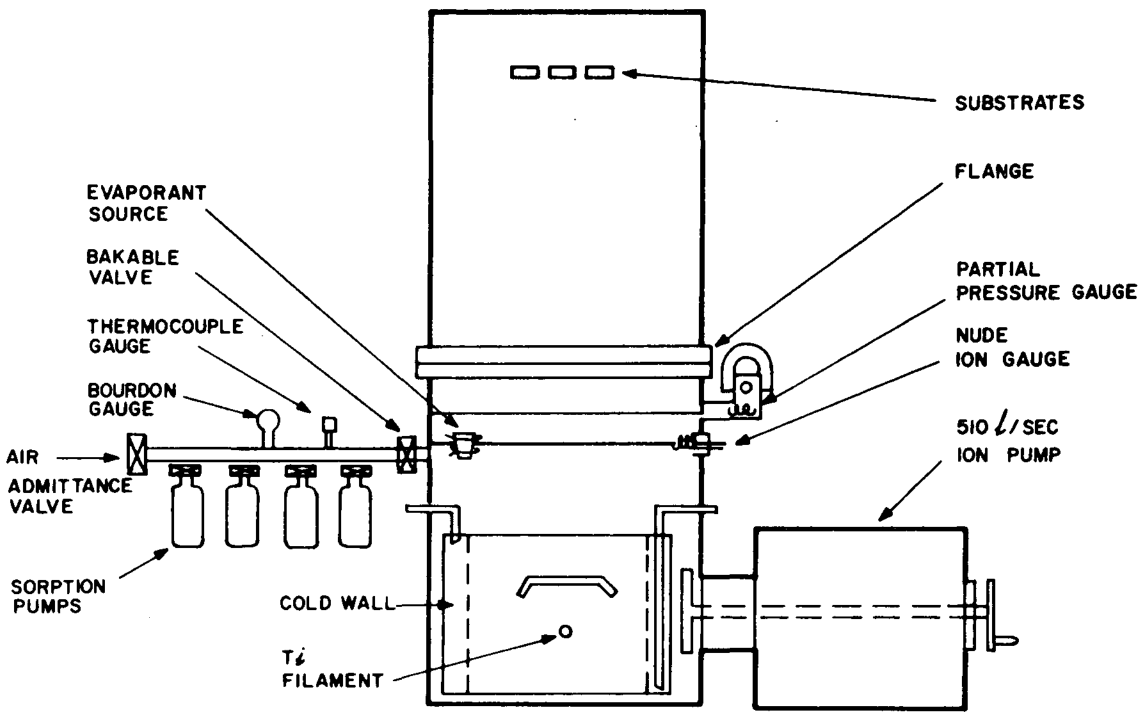


Fig. 8. The ultrahigh vacuum system.

After the bake-out, the only significant gases that can be detected with the partial pressure gauge are nitrogen and hydrogen. This seems to be a suitable environment for evaporation of aluminum films under controlled conditions. The evaporant can be heated either by directly heating a filament or metal boat by passing a high current through it, or by electron bombardment. The latter method is preferred for all materials since alloying of tungsten from the filament with aluminum could be a source of impurities, although there is no evidence this has occurred. The electron beam evaporation source focuses a stream of electrons, by crossed electric and magnetic fields, onto the evaporant which is held in a water-cooled crucible. Because only the area which is being evaporated is heated, the evaporant in effect acts as its own crucible. We have found that evaporation takes place at lower beam currents, hence lower pressures, if the aluminum is insulated from the water-cooled crucible by another crucible made from HDA (a boron nitride-titanium diboride substance produced by Union Carbide Company).

The intense heat that is required to evaporate most materials generates a large amount of gas both from the evaporant and from the walls of the system. There are very few pumps which are capable of handling this gas load. We have estimated that our pumping speed would need to be increased to 10^7 ℓ/sec to cope with our typical gas loads. The high temperature bake-out considerably reduces the problem. It is also highly desirable to outgas the evaporants with heat just below the vapor point. Aluminum is relatively easy to outgas. It can be held in its molten state and is usually outgassed sufficiently after 3 to 5 hours. The dielectric materials are a greater problem, however. Their thermal conductivity is generally lower than for metals, and because of the fixed electron beam size and position in our configuration, it is difficult to get rid of gas without evaporating the material. Degassing combined with the small available crucibles renders the system incapable of producing very many layers per change. The very low heat allowed and low thermal conductivity require an outgassing time of from 10 to 20 hours with constant attention. To achieve the lowest pressure evaporations therefore requires nearly 10 days of preparation for all five crucibles in vacuum. This has two effects. There is a relatively low yield of data and results, and one is afraid to make experimental changes for fear of losing half of the month's experimental yield.

We have been able to evaporate in the system below 10^{-9} torr, but only at very low rates. The ratio of rate to pressure is about a factor of 5 below that which is most desirable. However, even at the slowest rates (approximately 0.02 nm/sec), the resulting films are of a quality that is comparable to, if not superior to, films prepared in the conventional manner. An unexpected bonus in using the ultrahigh vacuum system is an unusually hard adherence of films to the substrate. Generally speaking, the films cannot be removed except by polishing the surface clean with abrasives. The films are apparently more compact and perhaps have a higher density.

The operation of the coater is fairly straightforward, with one exception: We take great pains to avoid the glow discharge which is commonly associated with high pressure operation of the ion pumps. This can be avoided by roughing with the cryogenic sorption pumps to a lower than normal pressure. We try not to start the ion pump until the pressure has reached $\sim 7 \times 10^{-5}$ torr. We feel that this prevents contamination of the substrate by impurity ions in the glow discharge. A good cleaning procedure before installation of the substrates, followed by a high temperature bake-out in vacuum, appears to leave the substrate surfaces clean.

THE OPTICAL FILM THICKNESS MONITOR

The major problem with any thin film deposition process is the means by which the thickness of the film is monitored during deposition so that the final multilayer stack will have the desired properties. There are many ways of monitoring film thickness.[11] It is important that the quantities of interest be directly measured. We speak, for convenience, of a film thickness in nanometers, but we mean that it must have a certain reflectance, transmittance and phase change on reflection. We have elected to measure reflectance as the basic film property to be controlled.

The optical system

Generally speaking, the optical system is used only for transmission of energy, and the quality of images need not be considered. Light used to measure film reflectance must come only from the surface of interest, and must be free of contaminant light. The system must further be stable enough to prevent vibrations from confusing the measurements.

The use of ultrahigh vacuum imposes some restrictions on the monitoring system. We have found that first-surface mirrors do not last in the system regardless of overcoating. Damage seems to occur during high temperature bakeout. The reasons for this are not presently known, but they should be investigated, as this may be important for certain types of space flights where mirrors may be subject to heating from solar radiation. Another limitation with ultrahigh vacuum is the difficulty of providing for mechanical motion inside the vacuum. Mechanical motion feedthroughs exist but are expensive, and one is limited in the number of available feedthrough ports.

Fig. 9 is a schematic diagram of the system we have used. The light source S is imaged on the pinhole D_1. This light is then chopped mechanically at 90 Hz, and the pinhole is imaged on the monitor plate G by the lens L_2 after being bent by the prism P_1. It is essential that the light be chopped as close to the source as possible so that it can easily be distinguished from the bright background light in the chamber which arises from ionization gauge filaments and the evaporation sources. The light reflected from the monitor plate is returned out through a feedthrough and imaged on the entrance *slit* of of a monochromator. An end-on photomultiplier senses the light at the exit slit. It is necessary to have the monochromator or filter at the photodetector to protect it from the bright light inside the chamber during evaporation.

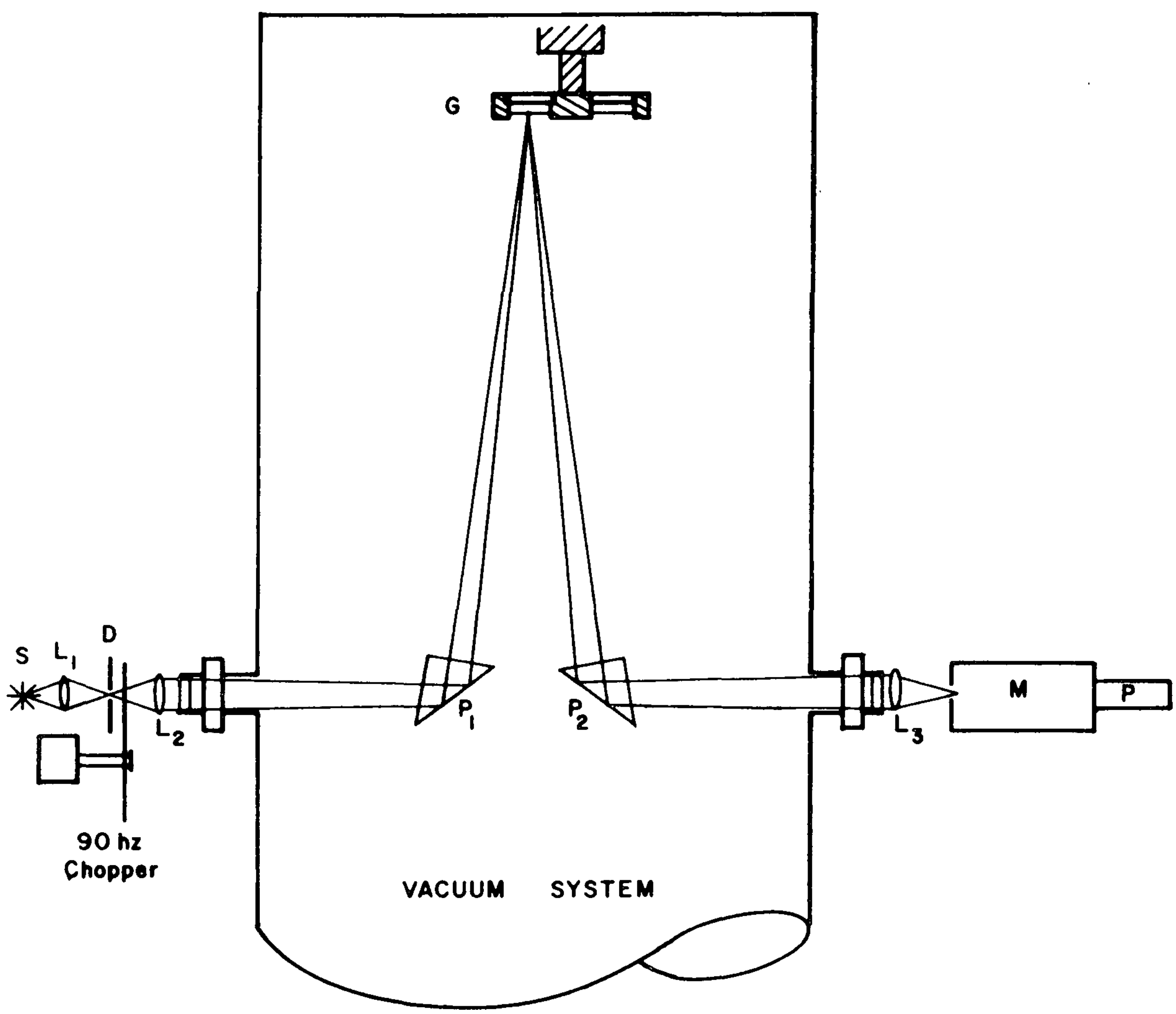


Fig. 9. Schematic diagram of the optical components of the monitor system.

The monitor system electronics

The ability to monitor and control the film thickness during evaporation is limited in accuracy by a combination of the inherent quality of the photometer electronics and the skill of the operator. It is desirable to let the human element be the limiting factor.

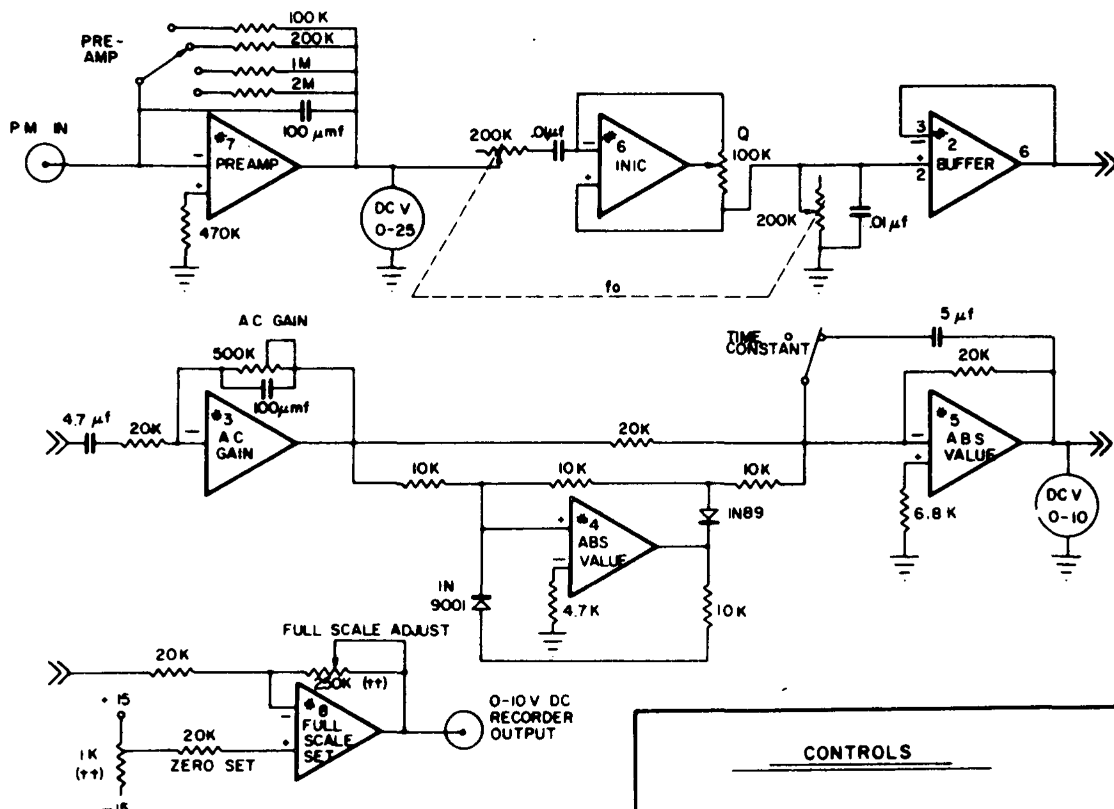
Change in reflectance with film thickness may take two forms. For dielectric layers, the reflectance changes approximately as a sine wave. For metals, the reflectance generally continously increases in a nonlinear manner. In some instances, in multilayer work, the reflectance of a stack will decrease to a minimum before increasing. When working with all-dielectric stacks that involve only quarter-wave layers, one evaporates to maxima or minima in the reflectance. As discussed above, with metals, the maxima and minima occur at the "effective" quarter-wave positions. Thus, for metal-dielectric multilayers, one must evaporate at one time or another to specific reflectance values rather than maxima or minima. For this reason, the monitor electronics must be linear and accurate over a wide dynamic range.

A typical requirement for a DMD evaporation might be to evaporate from a reflectance of 0.082 to a minimum of 0.053 and then evaporate from 0.053 to 0.620. One must be able to amplify the small reflectance changes so that they can be seen easily.

The electronic circuit, developed with support from grant NSG-732, is shown in Fig. 10. The circuit is built upon an assemblage of seven operational amplifiers. The signal from the photomultiplier is a negative current: A small dc current in phase with the 90 Hz signal combined with the noise background. The current signal is converted to a voltage which is the product of the input current and the resistor chosen at the preamplifier (#7). We select the 90 Hz signal by the active filter (#6) for which the central frequency and quiescence are initially adjusted. The signal is inverted by the buffer circuit (#2) and amplified by the ac amplifier (#3). The amount of amplification is set by adjustment of the 500 kΩ 10-turn potentiometer. Absolute value circuits (#4 and #5) convert the ac signal to a dc voltage which is proportional to the peak-to-peak difference in the ac signal. The dc signal passes through an amplifier (#8) and is added to a positive or negative zero bias signal for presentation on a strip chart recorder. By proper adjustment of the full scale, zero level, and gain potentiometers, a wide range of reflectance levels and reflectance changes can be recorded on a

10-inch chart. The preamplifier resistance is selected to provide a small enough signal so that later stages of amplification will not saturate.

The system has been shown to be linear to ±1% over a range of better than 1000:1 and has the versatility required for our monitoring work. Monitor noise is generally a serious problem, but for this system less than 0.1% noise is observed.



CONTROLS

1.	A C GAIN	DIAL
2	ZERO SET	"
3.	F. S. SET	"
4	POWER	DPDT
8.	Q CONTROL	POT
5.	PRE-AMP	ROTARY
6.	T SELECT	S & ST

Fig. 10. Amplifier electronics for optical film thickness monitor.

EXPERIMENTAL RESULTS

Three basic questions must be answered from observations of the experimental results. First, there is the possibility that optical properties (optical constants in particular) of films which are evaporated in ultrahigh vacuum are different from those of films prepared in more conventional vacuum systems. Second, we know that optical constants of very thin metal films are not the same as those measured for thick films or for bulk materials: what is the thinnest film that can be used which will have the same optical constants as those used for calculations? Finally, the filter calculations discussed above should be shown to agree with actual results, and filter production must be feasible for use in actual applications.

Properties of single films

Several films of several different materials have been prepared in the ultrahigh vacuum chamber under a variety of conditions. The two main parameters which we varied were the evaporation rate and the pressure. Because of pumping limitations of our chamber, we were not able to vary these parameters independently. The highest rates of evaporation were achieved only at higher pressures.

The properties of the aluminum films are of the greatest concern. We have needed to reduce the rate of evaporation to a point where the film thicknesses can be accurately monitored and controlled. The deposition rates we investigated ranged from about 0.01 nm/sec to 10 nm/sec. The rates are inferred from the measurements of film thicknesses and the total evaporation time. It is possible that the rates were nonuniform; however, by keeping the power on the electron beam source constant, the rate should be nominally constant. Pressures during evaporation ranged from 10^{-9} torr to 10^{-5} torr.

The observations we made were as follows: general observations of the film and its durability, reflectance and transmittance, and visual inspection of the films for scattering or roughness. The scattering observations and durability are only subjective comparisons.

Generally speaking, all aluminum films evaporated in the ultrahigh vacuum chamber were durable and free from excessive scattering. The films were not readily removed by washing in a sodium hydroxide solution, even after being exposed to air for several months. This indicates that the films are of relatively high density and that any spontaneous formation of aluminum oxide is limited to a thin surface layer.

The reflectance of an aluminum film evaporated at the start of the program was measured in the vacuum ultraviolet. Measuring difficulties at that time caused minute-to-minute changes in measured reflectivity at Lyman α (121.6 nm), so final data were not recorded. The sample had been exposed to air for about 2 hours and had been in the vacuum system for 3 days after evaporation. The initial reflectance which we observed, however, may have been as high as 0.80. These observations should be confirmed. A slow time decay of ultraviolet reflectance could be useful in some situations. After the reflectance had stabilized, the measured reflectance is as shown in Fig. 11 in the vacuum ultraviolet. At wavelengths longer than 200 nm, the reflectance is the same as films prepared under older "ideal" conditions (oil-pumped system at 10^{-5} torr at high rates). Our measurements of reflectance are limited to an accuracy of about ±2%, so detailed comparisons are not possible. We do observe that the reflectance of the ultrahigh vacuum aluminum films is slightly higher than those we prepare under normal conditions.

The best material for the dielectric layers in ultraviolet interference filters is magnesium fluoride. Although, in crystal form, lithium fluoride is transparent at shorter wavelengths, it was not considered here because it is slightly water soluble and less durable. The transmittance of magnesium fluoride films prepared in ultrahigh vacuum has been measured and can be considered to be free from absorption for all wavelengths from the infrared to 120 nm. The optical properties which we observed were essentially the same as those observed for films prepared under other conditions. Since we wish to form filters consisting of alternating layers of aluminum and magnesium fluoride, we avoid heating the substrates in order to obtain the best optical properties of the aluminum. All of our evaporations were on substrates at room temperature ($\sim$ 20°C). These films were durable and relatively free from scattering. Although it is generally recommended that the best magnesium fluoride films are prepared by evaporation onto warm ($\sim$ 300°C) substrates, we have not found that this is necessary to obtain durable films.

One problem encountered was that properties of combined films often indicated that they were more absorbing than they should have been according to single film observations and the theory. This is ascribed to impurities.

We have experienced difficulties in obtaining pure films when two materials are evaporated during the same vacuum cycle. Both aluminum and

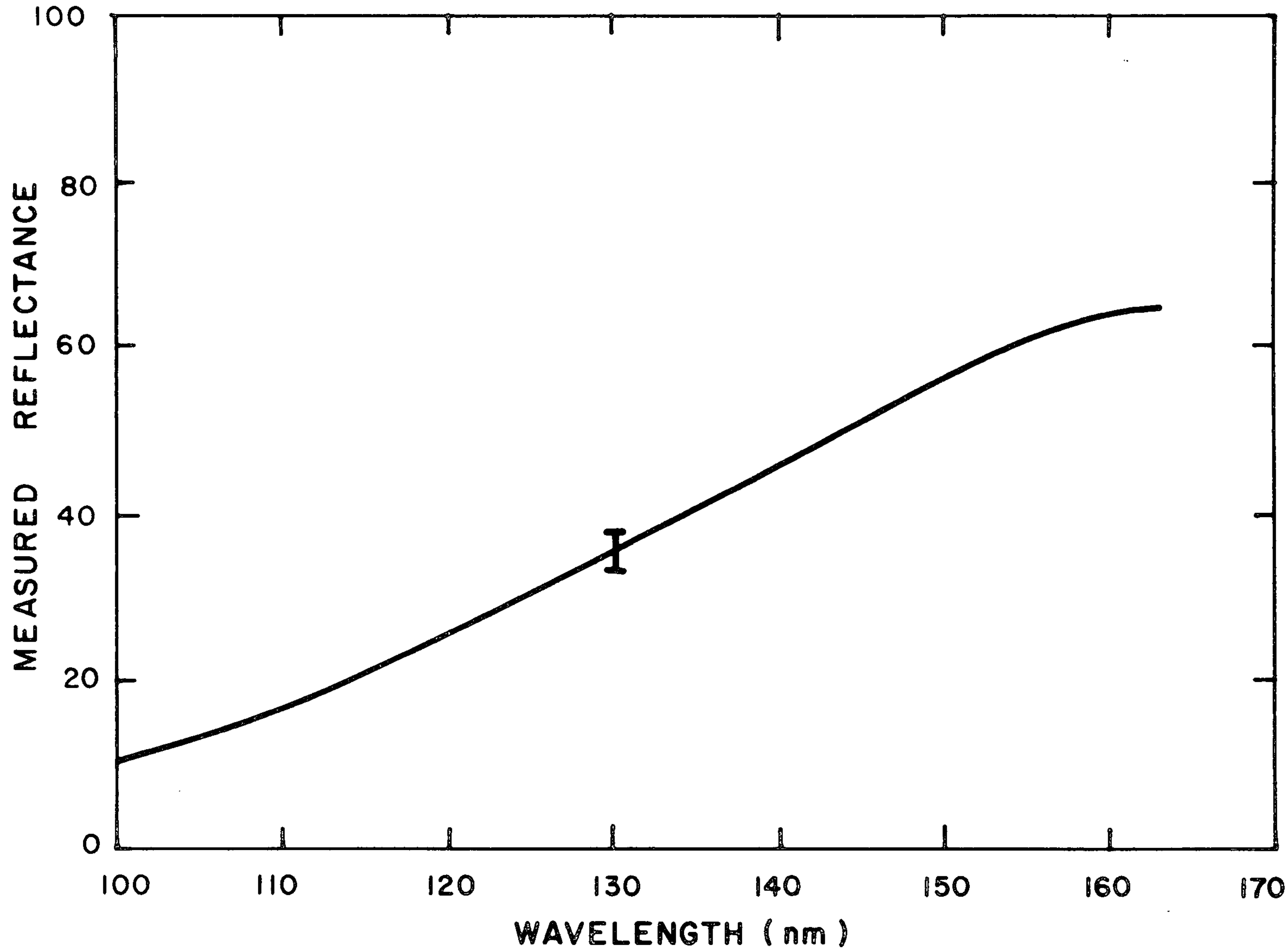


Fig. 11. Reflectance of an aluminum film measured in the vacuum ultraviolet.

magnesium fluoride films appear to be more absorbing than when they are evaporated during separate cycles. The apparent difference is due to a mixing of the materials on the hearth of the electron beam gun. We normally assume that materials in vapor form will travel in straight lines, sticking to the first surface that they hit. It is possible that some of the molecules are reflected from surfaces and appear not to travel in straight lines. This is thought to be only a minor source of contamination, however. A more important problem appears to arise from charged molecules which are deflected by the electric and magnetic fields near the vapor source. The effect is most evident for aluminum, where, after some time, we can observe a heavy deposit of aluminum near the bottom of the chamber where it is "impossible" for the atoms to condense. Apparently, some molecules migrate from one crucible to another during evaporation. This effect is lessened by greatly enlarging the shields between the crucibles. We have been able to control this effect to a large extent in this manner.

Another problem is that we have difficulty getting enough material into the evaporation region of the electron gun to be able to deposit as many layers as desired. This is due to the nature of the electron gun (Varian Associates Model 980-0005), which has five crucibles that can be moved in front of the filament, and uses a fixed accelerating potential and magnetic field. With the fixed field configuration, it is impossible to change the focus of the beam or the position with respect to the crucible. Shifting the crucible distorts the fields in such a manner that the electrons still hit the center of the crucible. Evaporation occurs only over a small (about 5 to 10 mm wide) area, leaving a large amount of material around the edge which cannot be evaporated. We have tried to evaporate from conducting crucibles in the manner of resistance heated sources, but the boats have evaporated before enough material has evaporated. There is a noticeable amount of contamination from the boat in these instances. We have also tried to premelt the evaporant in a vacuum furnace so that we would be evaporating from a solid piece. When this is done, the solid usually falls apart from thermal stress, leaving less material than when a powdered form is used.

The obvious solution is to use an electron gun with a beam control. This requires an electromagnet to produce the field. None of the manufacturers of this type of gun recommend their product for ultrahigh vacuum systems such as ours. Further experimentation with electrostatic deflection will have to be done before this problem can be solved. We are therefore presently limited to investigating designs that contain only a few dielectric layers.

Contamination of dielectric material is easily observed during deposition when the films are deposited directly on a glass monitor slide (without metal films). For a homogeneous nonabsorbing film, the reflectance varies nearly sinusoidally with thickness. When the film is slightly absorbing, the maxima and minima do not have constant values.

We have concluded from our observations of single films that evaporation in a clean ultrahigh vacuum system gives films which have nearly the same optical properties as those evaporated in a more conventional oil-pumped system. The optical constants are apparently close enough to published values that they may be used for computations. Good optical properties of aluminum may be obtained with very low evaporation rates and low pressures during evaporation. The physical properties of these films are at least satisfactory and quite possibly are superior to those prepared under more normal conditions.

Properties of very thin metal films

The filter designs discussed in other sections of this report require semitransparent films for most of the metal layers. For the MRF's, the film thickness should be about 20 nm. This thickness has been used for many MDM type filters with moderate success. The optical constants of films thinner than 20 nm may change with thickness, however.[12] The DMD filters require thicknesses between 4 and 5 nm to realize optimum theoretical characteristics. Whether the optical constants of aluminum are a function of the thickness for such thin films had not been determined for ultrahigh vacuum evaporations. The optical constants given in the table on page 5 are reported to be valid for films as thin as 10 nm when evaporated under normal conditions.[13] It had not been determined whether the limit was a function of the evaporation conditions, however.

There are several problems associated with working with very thin aluminum films. Probably the greatest problem is that the pure metal is very reactive. An oxide layer forms very rapidly on the surface, and this affects the optical properties of the "films." When the film is very thin, it is difficult to determine whether there is any pure material left. The thickness of the film may be affected because of the increase in the total number of atoms. Changes in density also cause uncertainty in the nature of the film.

We have investigated the properties of DMD single periods for different metal thicknesses. In this way, we can study the properties of metal films in the environment in which they will eventually be used. In principle, the optical constants of a metal film can be determined from a knowledge of three quantities. One of the ordinarily necessary parameters is the thickness of the film. Film thicknesses of 4 to 5 nm are, at best, difficult to measure with any precision. We have found that such measurements do not need to be made to determine a "limit" for the thickness of the film that will have the "thick" film optical constants. We are unable, however, to determine the optical constants as a function of film thickness; only deviation from assumed values can be determined. The method used is to evaporate a number of separate DMD periods with different metal thicknesses. The outside dielectric layer protects the aluminum from oxidation. The "thickness" of the metal layer is chosen by evaporating to a certain value of the reflectance. Computations of the reflectance for several metal thicknesses are used as a guide. The reflectance and transmittance of the DMD period are then measured and compared to all possible values computed from the thick-film optical constants (see table on page 5). Fig. 12 shows a plot of the reflectance vs transmittance of DMD periods where the quarter-wave optical thicknesses of the D layers are 400 nm and the measurements are at 400 nm. Several thicknesses are labeled along the theoretical curve, which represents all possible reflectance and transmittance values. The measured points show the variation. From the data, we can infer that thicknesses greater than 9 nm can be considered to have the optical constants given in the table. It was possible to predict the "thickness" of the film for these values before measurement. There was no indication, during the evaporation, that oxide layers were responsible for the deviations of measured and computed values. Under less-than-ideal conditions, it is possible to observe the change in reflectance with time of the unprotected aluminum layers when the films are very thin. Such changes were not observed with these films for periods up to 10 minutes in ultrahigh vacuum.

These evaporations were done in the UHV chamber using the techniques described above with the pressure and evaporation rates among the higher values. The results are relatively insensitive to small (about one order of magnitude) changes in the pressure. Typical values for the aluminum films were a total pressure of 3×10^{-6} torr and an evaporation rate of about 10 nm/min.

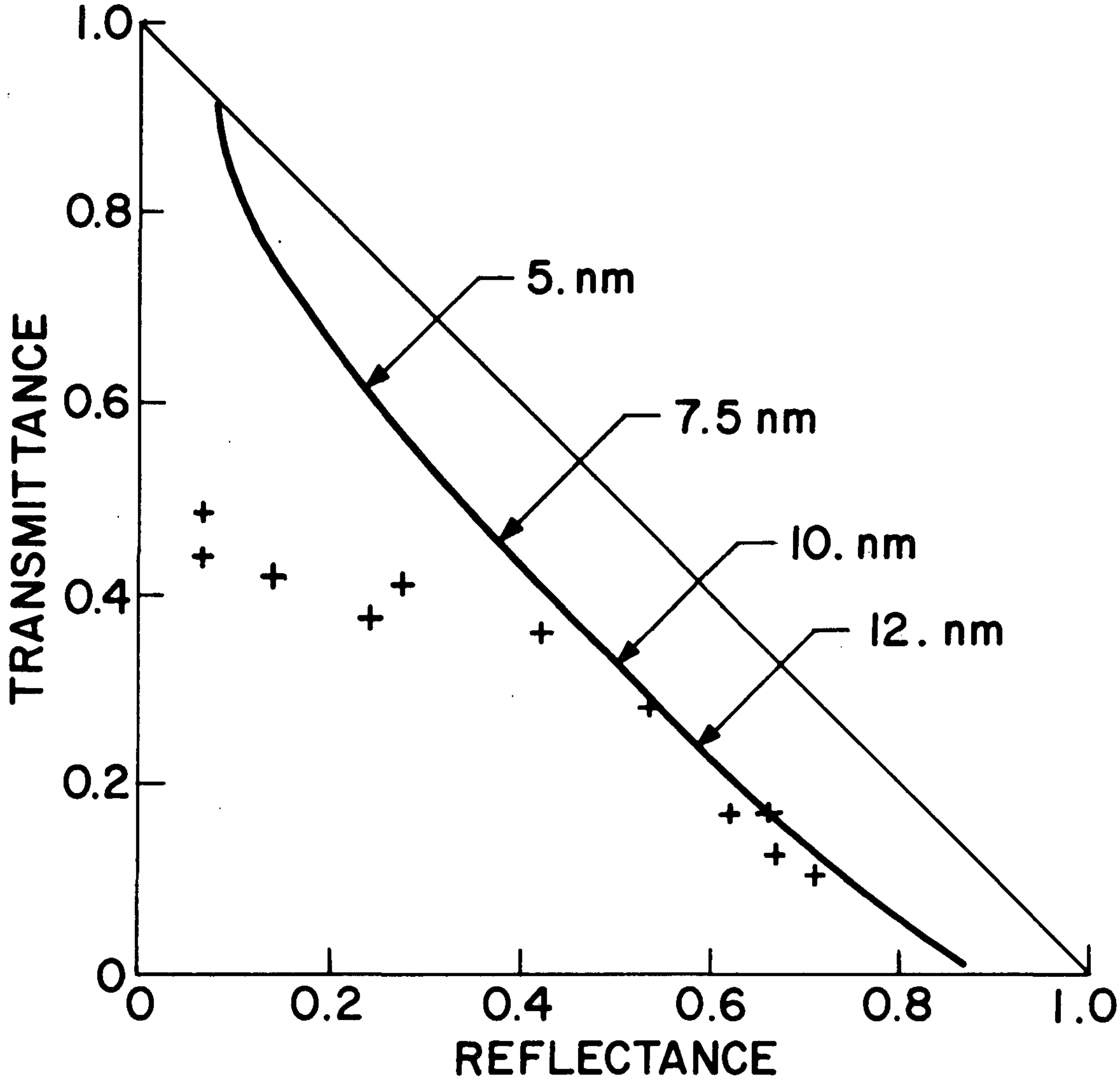


Fig. 12. Reflectance vs transmittance of dielectric-metal-dielectric filter stacks whose D layers are 400 nm thick.

Properties of mirror reflection filters

The three-layer mirror reflection filter will be the easiest type of filter to make. First, the number of layers is minimal, and second, the reflectance is the only quantity which needs to be compared with the theoretical value. As discussed earlier, however, there have been significant differences between theoretical and measured results.

One of the most difficult problems in making an MRF is the monitoring of the film thicknesses. As discussed earlier, the minimum reflectance and the wavelength of the minimum depend on many factors, and slight errors in the dielectric thickness or unexpected changes in the optical constants of the semitransparent metal layer can cause large errors in the thickness of the final layer.

We have had good success monitoring each layer on a separate piece of glass as it is deposited. The main disadvantage in this method is that one cannot compensate for small errors as the filter is formed.

An example of an MRF with a semitransparent aluminum layer that corresponds closely to the theoretical prediction (Fig. 3) is shown in Fig. 13. The evaporation conditions used to obtain this result are essentially the same as those described in the previous section. There is a 45-nm-thick protective layer of magnesium fluoride over the semitransparent metal layer. This layer has only a small effect on the properties of the filter.

The role of impurities in dielectric films is demonstrated in Fig. 14, which is essentially the same filter as above except that there has been some contamination. The increase in absorption is dramatic, even though it was only slightly observable during evaporation. The reason for the enhanced effect is that the dielectric layer is inside a resonant cavity where the electric field should build up. The absorption has two effects. In addition to decreasing the filter efficiency, there is an error in the thickness of the dielectric layer of the final filter which is caused by a change in the thickness where the monitor reflectance is a minimum, due to the fact that the phase changes on reflection are no longer 180° as required. From the shape of the curve, we can conclude that the optical constants of the aluminum layer are not seriously affected. These results still differ from previous results, which gave a high peak reflectance, symmetrically shaped reflectance band, and low background (wide reflection minima). These characteristics were not observed in this project without a change in the materials used.

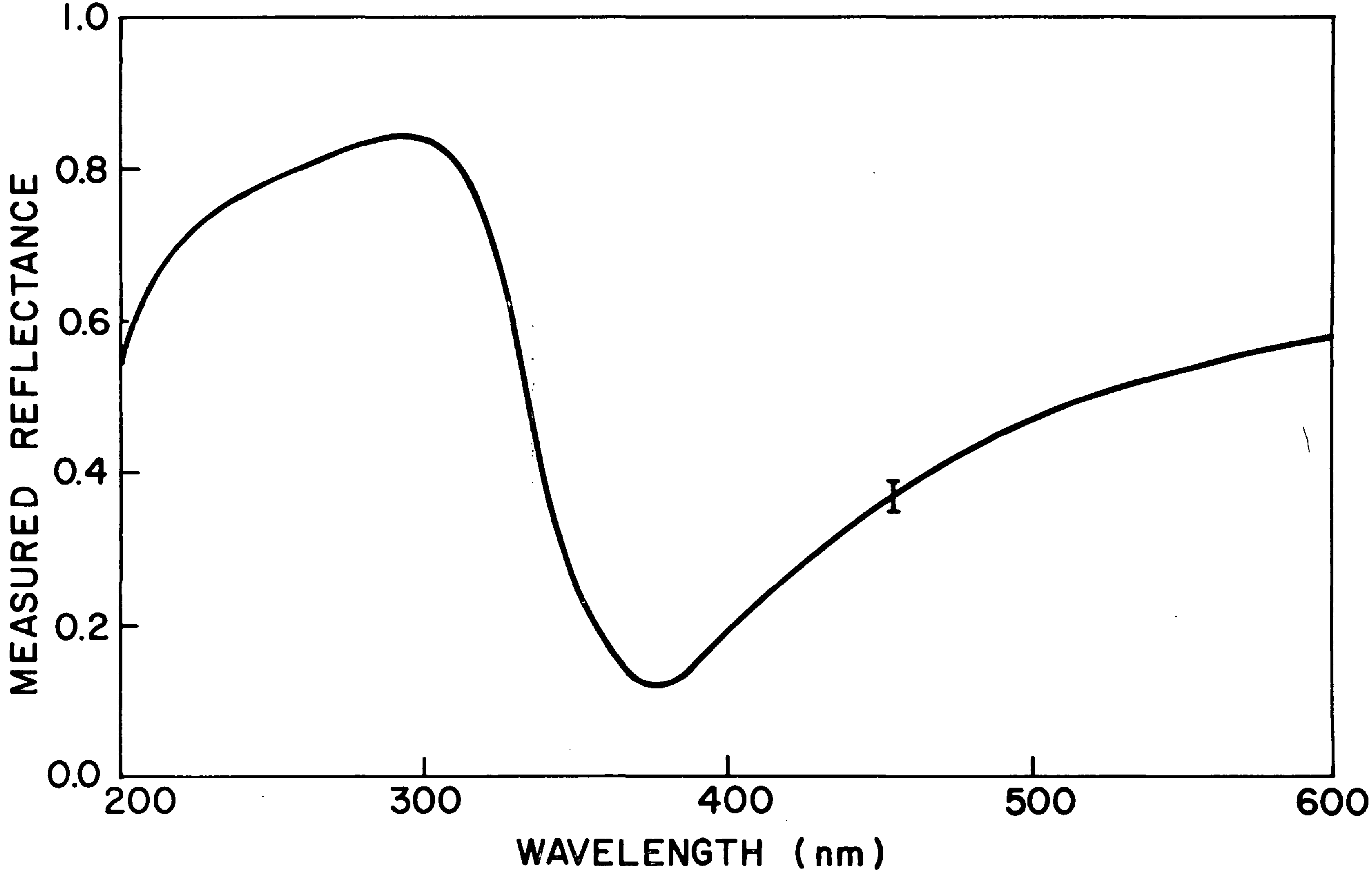


Fig. 13. Mirror reflection filter with a semitransparent aluminum layer.

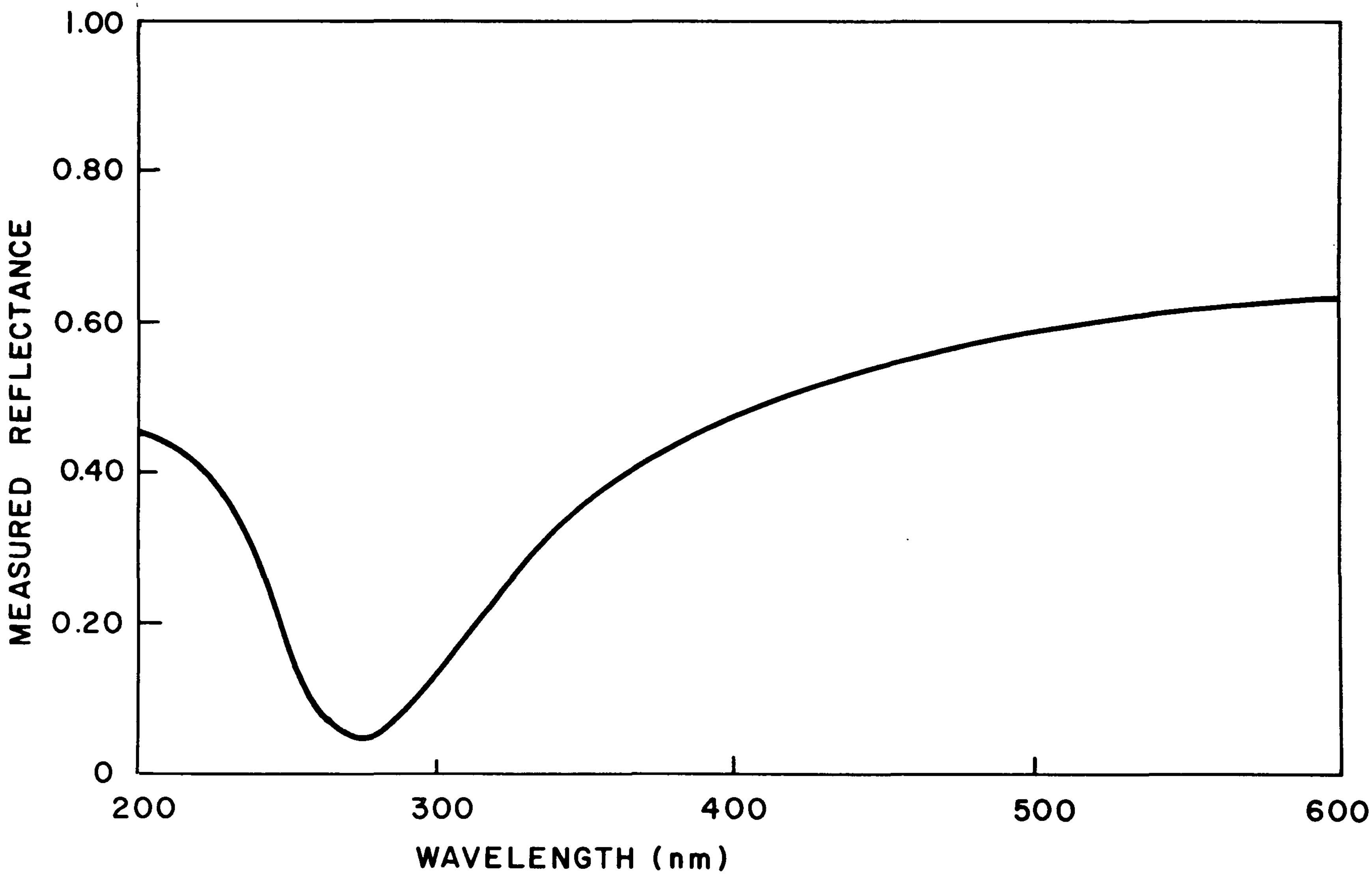


Fig. 14. Role of impurities in dielectric film.

Our earlier conclusions that solar-blind mirrors based upon only aluminum and magnesium fluoride cannot be effectively produced in our highly controlled conditions appears to be valid. It has been shown that changing the material for the semitransparent metal layer can produce a filter which would be a better solar-blind mirror. A filter with chromium, magnesium fluoride, and aluminum has been made; its reflectance is shown in Fig. 15. The result is close to that predicted although there is some evidence that the dielectric was slightly absorbing. Use of chromium would be recommended for solar-blind mirrors.

The observed decrease in the reflectance of unprotected aluminum immediately after evaporation can be explained by an increase in the real part of the complex refractive index. The aluminum thus becomes more like chromium. We can perhaps conclude that Turner's earlier experimental results were for a chromiumlike semitransparent film. That experimental results which agree with computed results can be achieved has been demonstrated by this research.

Properties of reflection filters with more than three layers

Design possiblities for ultraviolet filters with more layers based on the DMD period have been discussed. Application of these designs to solar-blind mirrors may not be optimal using aluminum and magnesium fluoride with present-day techniques and coating chamber facilities. The "minimum" allowed thickness for aluminum films is more than twice that required for the best designs. It has not been established whether the present limitations are due to techniques or basic physical properties. That the films 5 nm thick are different is not really surprising since they would be only about 10 unit cells thick (the size of the unit cell being 0.5 nm).

We were able, however, to make some of the thicker DMD stacks to compare with theoretical calculations. Such comparisons allow us to draw some definitive conclusions regarding the properties of the materials and the validity of our calculations.

Filters of DMD stacks with one to four periods have been made, with a 10 nm metal layer thickness. The properties of the single period stack were discussed above, and further measurements confirmed the predictions of Fig. 5(a). An example of a two-period stack is shown in Fig. 16. This result can be considered to be in agreeement with the computed result shown in Fig. 5(b). The absolute value of the differences between theory and observation

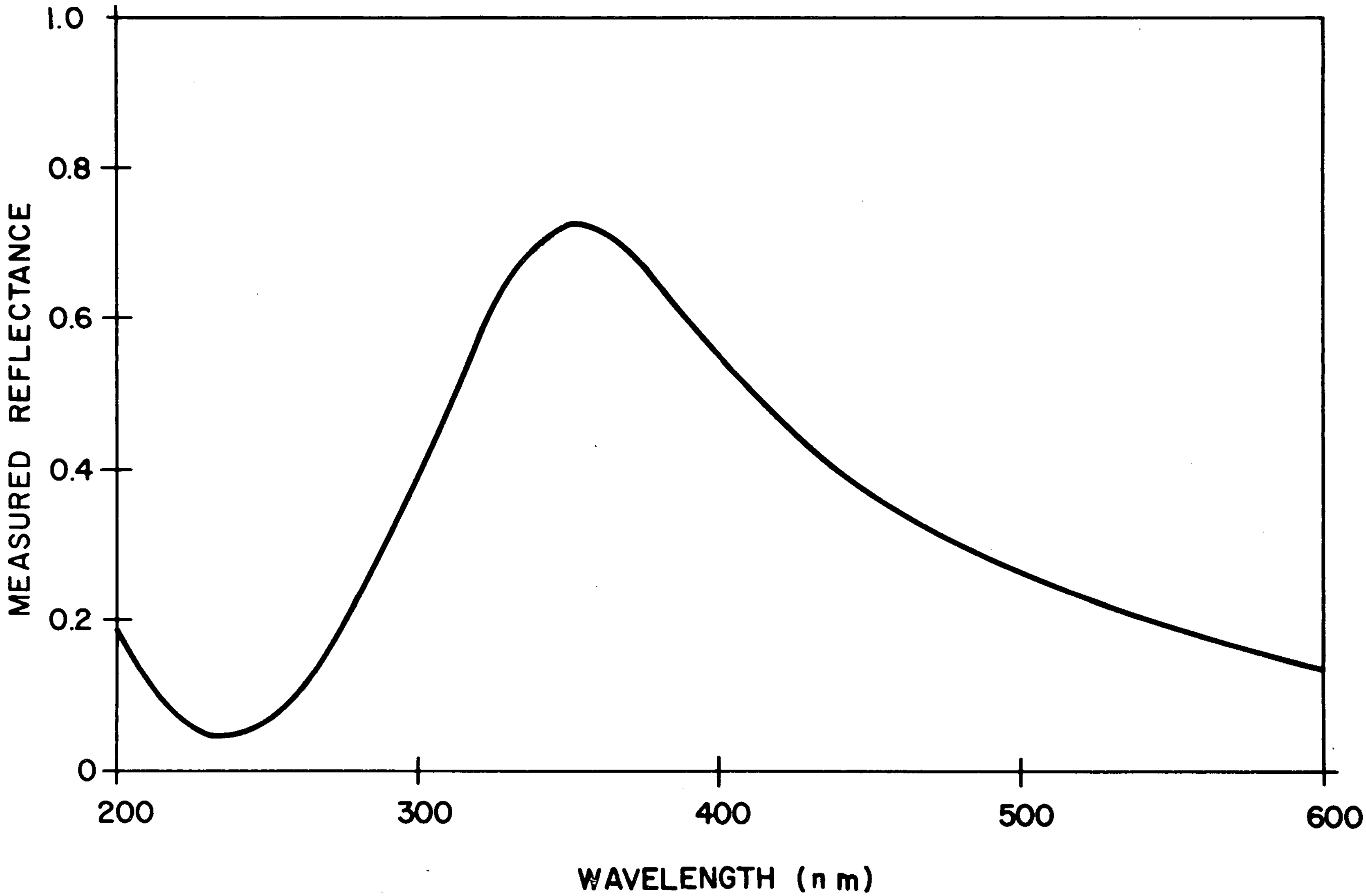


Fig. 15. Reflectance of a filter with chromium, magnesium fluoride, and aluminum.

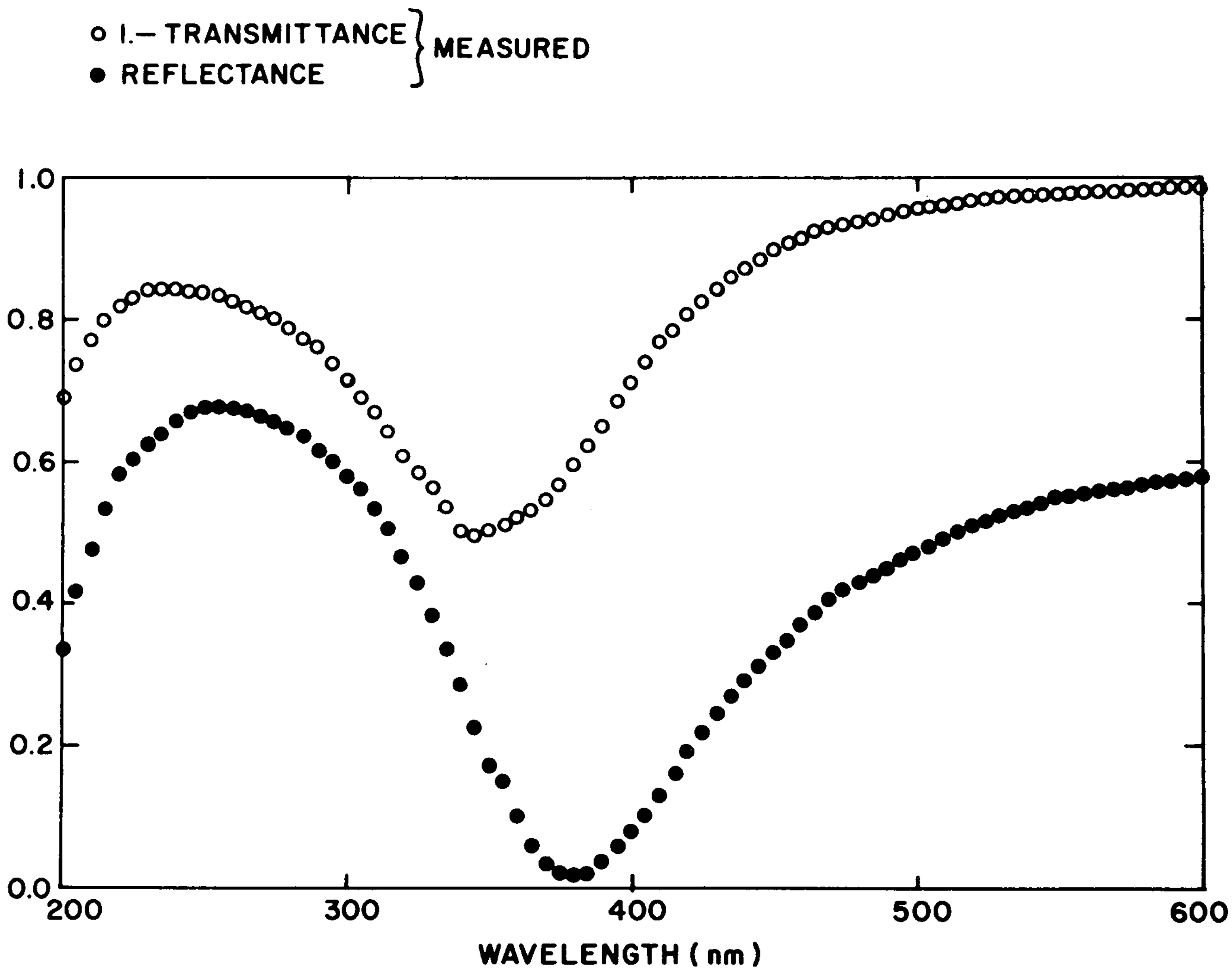


Fig. 16. Example of a $(DMD)^2$ filter.

is less than 0.03, which is only slightly greater than the uncertainty in the measurements. The differences, though slight, are thought to be real. Their source is not known, however. There may be some residual absorption in the dielectric layers. It is also possible that the aluminum-magnesium fluoride interfaces are not as abrupt as assumed. The chemically active aluminum surface may be interacting with the magnesium fluoride vapor as the dielectric film condenses. For the double period, however, such effects can be considered negligible.

Figs. 17 and 18 show the results of measurements of 3 and 4 period DMD stacks, respectively. Several of the features which were predicted above can be observed. As the number of periods is increased, the peak reflectance rises, and the high reflection band near 250 nm becomes sharper. Since there is no transmittance at long wavelengths, nothing can be done about the high long wave reflectance by adding more similar periods. The exact features of the three- and four-period stacks were not as close to the predicted values as was the case with the two-period stack. The variances can be attributed to a combination of a 1 to 5% increase in the real part of the refractive index of the metal layers, and a 5% or less error in the thicknesses of the dielectric layers. Such errors are within the expected error. To maintain an accuracy in the dielectric layer thickness of ±5% or better, one must be able to determine the minimum to an accuracy of better than ±0.0003 absolute reflectance. With the scale expansion features of the present monitor electronics, this represents a reasonable limit.

Although the properties of these filters correspond closely to the computed properties, they do not represent an optimum solar-blind mirror. According to the theory, a better result would be obtained by decreasing the thickness of the metal layers. We demonstrated above that we could not expect the computed results because of the thickness dependence of the optical constants. Since we have not measured the refractive indices, we cannot compute, with confidence, any filter properties for metal layers thinner than 10 nm. We did, however, make a DMD stack with five periods and a metal thickness of about 5 nm. The measured reflectance and transmittance are shown in Fig. 19. The most interesting feature to note is the low visible reflectance. That the peak reflectance is not high is not surprising since the metal is probably more absorbing that it would be if it were thicker.

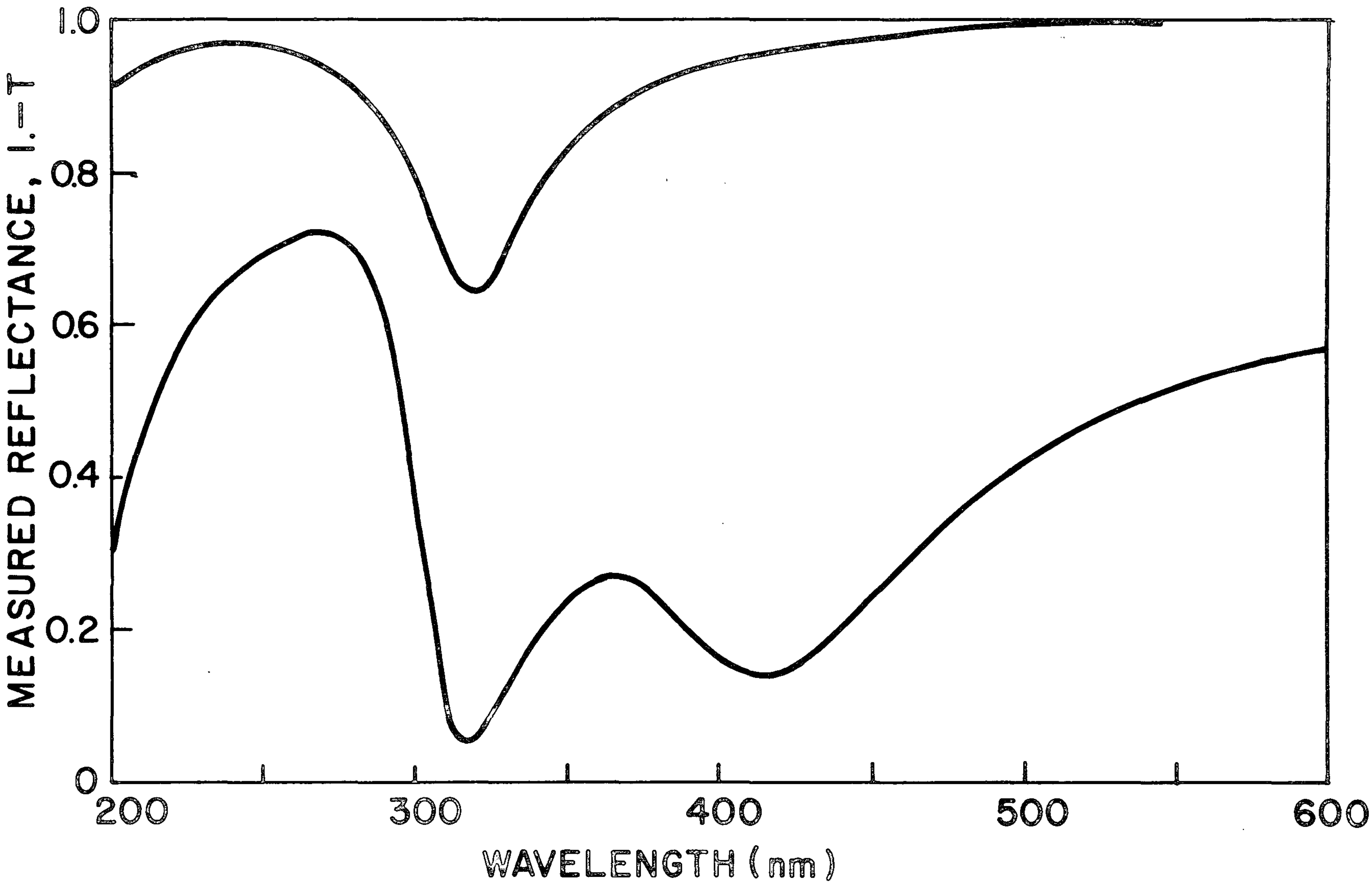


Fig. 17. Measurements of a three-period DMD stack.

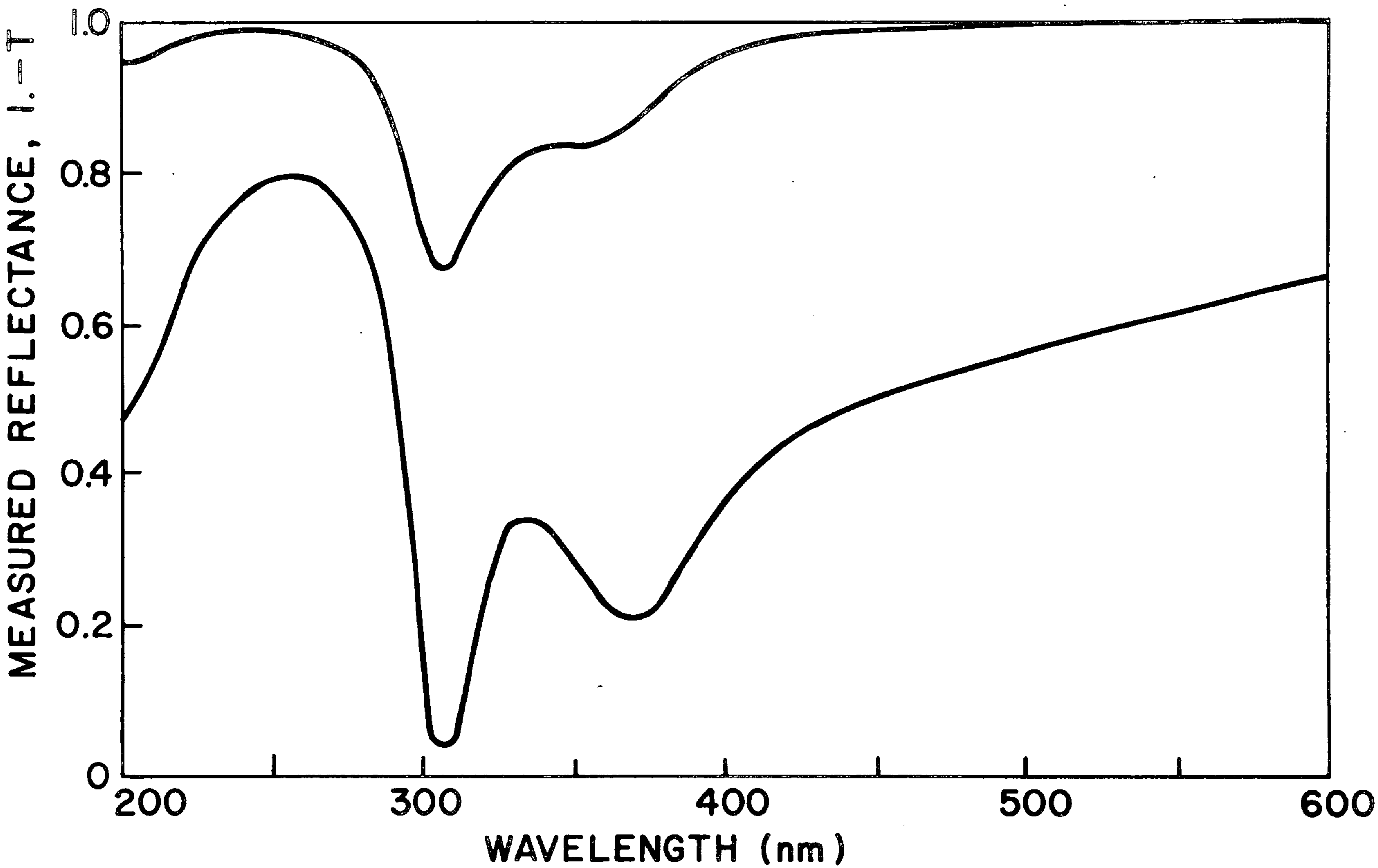


Fig. 18. Measurements of a four-period DMD stack.

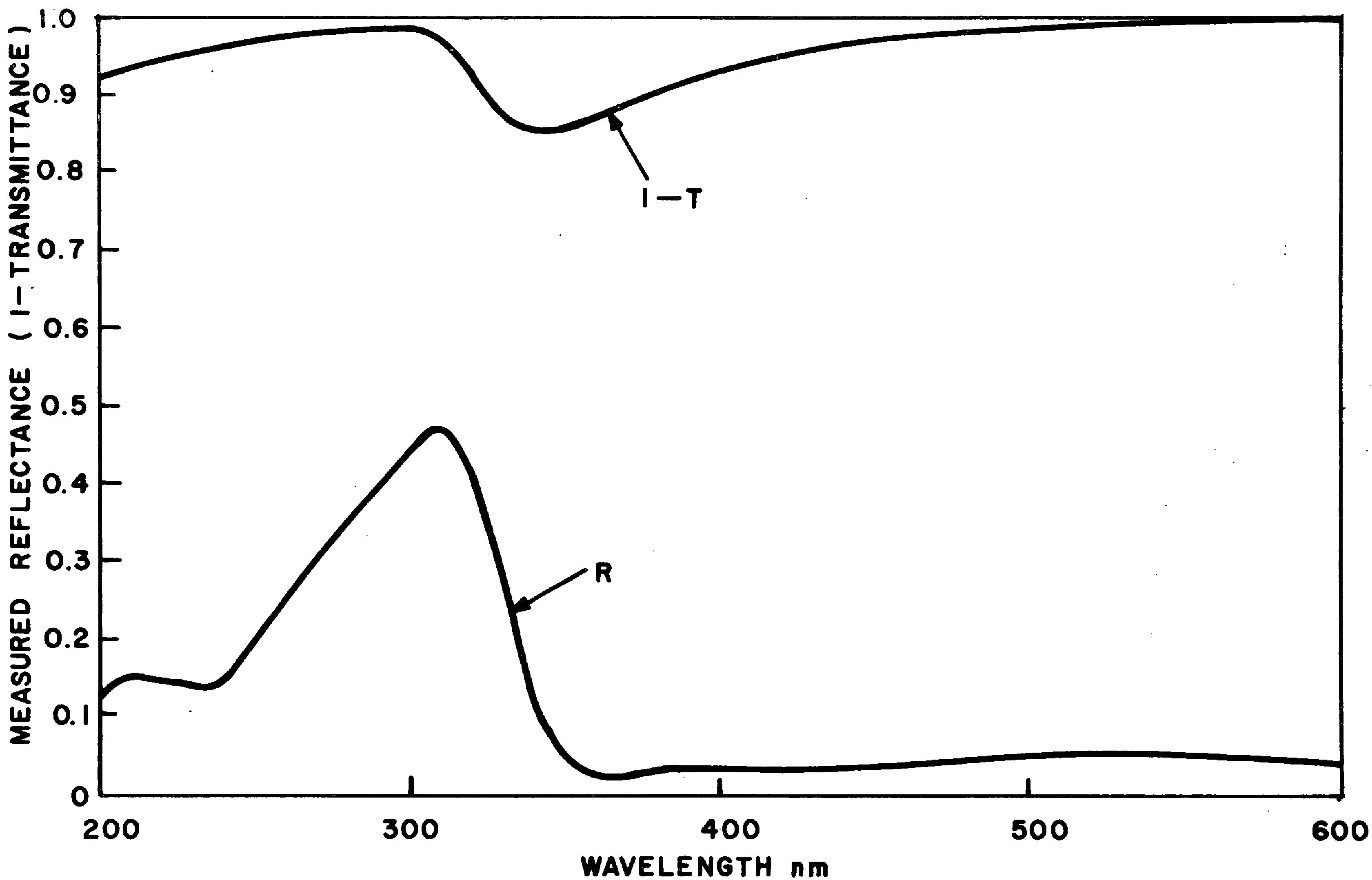


Fig. 19. Reflectance and transmittance of a DMD stack of five periods and metal thickness of about 5 nm.

DISCUSSION AND RECOMMENDATIONS FOR FURTHER WORK

We have studied the properties of two types of interference filters in this research to better understand their properties and to determine whether it might be feasible to make mirrors which reflect only ultraviolet light. Techniques for both the design and fabrication of such mirrors have been developed, and it has been established, for the first time, that under certain conditions the properties of metal-dielectric interference filters can be predicted from the simple theory of homogeneous thin films.

We have found that the thickness limit for thin aluminum films is 9 nm. Films thicker than this value will have the optical constants which have been previously published. Detailed measurements of the indices of thinner films should be made, as it appears possible to use the material to advantage to obtain solar-blind mirrors. One method that is attractive without further extensive work is to use thick (10 to 12 nm) aluminum films in a DMD stack with about five periods, and over-coat this with one or more periods using thin ($\sim$5 nm) metal layers. Such a combination should leave the desirable square high reflectance at short wavelength and rapidly kills the long wave reflection. This should be effective because the thin metal films will be located at the electric vector modes at short wavelengths and at the antinodes at longer wavelengths. If measurement of the indices proves too difficult, an empirical determination of such a design is feasible since there are, at most, only one or two metal thicknesses as variables. Work of this sort is continuing. It should also be determined whether good solar-blind mirrors could be found by using combinations of two dissimilar metals as we did for the MRF's.

We have found that the properties of the materials utilized are very good when evaporated in ultrahigh vacuum. Further work should be undertaken to improve these properties by changing evaporation parameters in a systematic way. Evaporation rate, residual gas atmosphere, and substrate temperature effects should be considered.

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Grant Number 19. June 15, 1966 $4,000

Investigator D. M. McEligot, Associate Professor
Department of Aerospace and Mechanical Engineering

Title: Nuclear Power for Space Systems and Vehicles

Summary:

The aims of this project are the understanding and prediction of turbulent transport properties as existing or expected in nuclear rocket reactors. The coupled energy, momentum, continuity, and integral continuity equations have been programmed for solution on the digital computer for the flow of gases in circular tubes, with strong property variation being represented via power law functions of temperature. Various turbulence models - eddy diffusivity and mixing length distributions - have been generalized for the prediction of effective thermal conductivities and effective viscosities in the equations. Results were compared to data for pre-cooled nitrogen heated to $T_w/T_i \approx 12$ and (T_w/T_b)peak ≈ 7; fair agreement is found.

Publications:

P.M. Magee and D.M. McEligot, "The Turbulent Thermal Entry with Gas Transport Property Variation", Trans. A.N.S., 10, 652 (1967)

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H.C. Reynolds, M.E. Davenport and D.M. McEligot, "Velocity Profiles and Eddy Diffusivities for Fully Developed, Turbulent, Low Reynolds Number Pipe Flow", ASME paper 68-WA/FE-34, 1968

H.C. Reynolds, T.B. Swearingen and D.M. McEligot, "Thermal Entry for Low Reynolds Number Turbulent Flow", J. Basic Eng., 91, 87-94 (1969)

D.M. McEligot, S.B. Smith and C.A. Bankston, "Quasi-Developed Turbulent Pipe Flow with Heat Transfer", J. Heat Transfer (in press), presented at Heat Transfer Conference, May 1970

Grant Number 20. June 15, 1966 $5,000

Investigator Roger C. Jones, Professor
Department of Electrical Engineering

Title: Separated Beam Plasma Amplification

Summary:

1. Review of the Concept: In considering beam-plasma microwave amplification in a gaseous plasma, the desire to go to higher and higher operational frequency meets, eventually, contradicting facts:

a. For the electron beam, the mean free path of an electron is inversely proportional to the gas pressure - and the mean free electron path must be longer than the tube dimensions.

b. Amplification occurs in the vicinity of

$$\omega_p = \sqrt{\frac{ne^2}{m\varepsilon_o}},$$

so the operational frequency is proportional to the square root of the pressure (assuming ionization percentage has been pushed to the limit).

The only way to overcome the above contradiction is to force the electron beam to travel in a physical space separate from the plasma. The electromagnetic interaction between plasma and beam is then weakened, and the object is to determine whether or not amplification will be possible under this condition.

2. Results:

a. Theoretical:

Mr. Peter Koert, a graduate student, was assigned the task of determining the conditions, if any, for which separated beam-plasma amplification would exist. He was able to analyze the lossless case (the neglect of

electron-molecule collisions), and it was found that this case did exhibit a "pole" of the usual type. However, this "pole" was multiplied by the beam current magnitude; as the singularity would disappear (and be replaced by a resonance function of finite magnitude) when losses were included, it could not be established positively (without a more exact analysis) that amplification would occur for feasible beam currents. Nevertheless, it looked likely, so design and construction of a tube proceeded.

b. Experimental:

A tube was constructed utilizing a plasma beam-mode discharge gun (with appropriate electrodes), a glass tube (with helical couplers) through which the beam was to be sent and a separate glass envelope enclosing said tube in which the plasma was to be created. This tube was connected to a vacuum-gas filling system, and all the leaks (of which several small variety existed) were eliminated. This is the point at which the project was delayed; we had sufficient funds so that we were able to construct (with the indefinite loan of two tranformers from Tucson Gas and Electric) a 15 KV, 500 MA power supply. However, we did not have sufficient funds to construct a solenoid magnet and associated power supply - said magnet being necessary for beam confinement. At this point the project was terminated, temporarily, for the lack of further funds. We have the large power supply (for the gun electrodes); we have the tube on the vacuum-gas filling system; but we do not have an appropriate magnet and supply to carry out the needed experimentation.

3. Conclusions: Thus, we were able to perform a first order analysis (lossless case), we were able to construct one (1) tube, and we were able to construct an appropriate high voltage, high current power supply. To continue the project, as we hope to do at some time in the future, we would require

funds for an appropriate magnet - as well as funds for computer and graduate student time to attempt a more exact analysis. Separated beam-plasma amplification is at the point where it looks promising, but extensive experimental and analytical work remains to establish its real feasibility.

Grant Number 21. August 12, 1966 $10,800

Investigator Stanley Bashkin, Professor
Department of Physics

Title: Beam Spectroscopy of Heavy Elements

Summary:

The purpose of this research is to study the optical spectra of heavy elements which have been excited by their passage through a thin film.

All of our information on the noble gases (helium, neon, argon, krypton, and xenon) is being assembled for publication in a single paper. The information will include:

1. measurements of wavelengths
2. Measurements of mean lives
3. Identification of levels

In addition, we have learned how to make, and have used, large numbers of beryllium foils as targets. In connection with this development, a visitor from the Naval Research Laboratory spent a week with us so as to learn the technique.

An apparatus has been developed for the determination of the absolute thickness of our carbon films.

The new accelerator has been placed in operation.

The program has been supported by grants from the Office of Naval Research and the National Aeronautics and Space Administration. The institional support was particularly helpful in obtaining our contract with ONR.

Graduate students who were supported in part by the Institutional Grant were H. Oona and D. Rickel. They both completed sufficient work for a

Master's thesis, but neither has written a thesis. R.A. Bowden, Jr., who worked on various phases of the project, with financial aid from one of our funds, also did enough work for a Master's thesis, but he received a Master's Degree without thesis.

Grant Number 22. July 12, 1966 $6,200

Investigator Quintus Fernando, Professor
Department of Chemistry

Title: Molecular Electrodeposition of Metal Complexes

Summary:

Films of metal complexes were electrodeposited from solutions containing an organic solvent such as isopropanol, and a hydrated transition metal salt and a chelating agent. In this study two types of chelating agents were employed: (a) azo dyes such as 1-(2-pyridylazo)-2-napthol which form charged metal complex species in solution, and (b) ligands such as dithiooximade which form polymeric metal complex species in solution. Three types of electrodes were used: (a) platinum, (b) conducting glass, (c) carbon foil.

The composition of the electrodeposited films was determined by chemical analysis. Mass spectrometry, ^{1}H n.m.r. spectra and absorption spectrophotometry were used to confirm the structure of the films.

The diffuse reflectance spectra of the films deposited on platinum electrodes was measured. The reflectance as well as the transmittance spectra of the films deposited on the conducting glass electrodes was measured simultaneously. Hence, the effect of film thickness on the transmittance and the reflectance spectra could be investigated.

Attempts were made to deposit oriented films of metal complexes and study their spectra in the manner described above.

A complex of nickel(II) and 1-(2-pyridylazo)-2-napthol (Ni-PAN), was readily deposited on a conducting glass electrode. The transmittance spectrum of this complex showed two bands at 568 mμ and at 530 mμ. The absorption

spectrum of the complex in ethanol solution, however, gave two bands at the identical locations, but the magnitudes of their molar absorptivities were reversed. An investigation of the following variables did not resolve this anomaly: film thickness, time of electrodeposition, current density, and concentration of the complex in the organic solvent. It was concluded, therefore, that the composition of the metal complex film differed from that of the metal complex in ethanol solution. Preliminary chemical analyses indicate the presence of hydroxo compounds of nickel(II) in the electrodeposited film. The films will be deposited under carefully controlled conditions in order to ensure that only one type of complex is electrodeposited.

A complex of nickel(II) and 4-(2-pyridylazo) resorcinol, (Ni-PAR), was also deposited on a conducting glass electrode under conditions that were similar to those used for the deposition of the NI-PAN complex. In this case the transmittance spectrum gave two bands at 500 mμ and 320 mμ, which corresponded almost exactly to the absorption spectrum of the 1:1 Ni-PAR complex in ethanol at elevated pH values. The analysis of the electrodeposited film, however, showed that it was not a pure 1:1 Ni-PAR complex.

At this stage of the investigation it was clear that unless a film with a uniform stoichiometry could be electrodeposited reproducibly, the spectral results would have little value. It was therefore decided to deposit the metal complex films under a variety of conditions and determine the chemical composition of the films. A simple spectrophotometric method was worked out for this purpose. The Ni-PAR complex is not formed in acid media; therefore, the ligand concentration (PAR) can be determined in the presence of nickel. Beer's Law was obeyed (at 400 mμ) in 1.0 M HCl between 6×10^{-6} M and 2×10^{-3} M nickel(II).

With the above spectrophotometric method, the composition of the electrodeposited complex was determined under various experimental conditions. When the PAN:Ni ratio was 2:1, or higher, no electrodeposited film was observed at pH>1.4. At pH values <1.4 a film was electrodeposited very slowly. When the PAN:Ni ration was 1:1, no deposit was observed at pH>2.5. The best deposits that were uniform and adherent were obtained when the Ni:PAR ratio was 1:1 and the pH was controlled between 1.0 and 1.6. A voltage range of 50-200 V was used and the time for electrodeposition was varied from 15 minutes to 24 hours. The addition of small amounts of water (5-15 0/0 v/v) to the isopropanol solution gave non-adherent deposits.

All the above results indicate that a mixture of compounds is being electrodeposited and that the NiPAR complex predominates. Future investigations will be directed towards eliminating this difficulty and forming a film of a single metal complex.

Grant Number 23. July 15, 1966 $1,300

Investigator J. E. McDonald, Professor
Department of Meteorology

Title: Unexplained Atmospheric Phenomena

Summary: The research work on this grant has been completed. Final Report was included in the third Semiannual Report.

Grant Number 24. September 6, 1966 $6,000

Investigator R. N. Carlile, Associate Professor
Department of Electrical Engineering

Title: A Study of Optical and Millimeter Wave Interaction with Thin Semi-Metal Films

Summary:

Our objective was to construct a thin single film of Bismuth approximately a few hundred Angstroms in thickness and to determine its equivalent permittivity at 20 GHz and 4.2°K. The Slater cavity perturbation technique will be used for the determination of the permittivity. Once the permittivity is known, the wave guiding properties of the single crystal film can be predicted.

As we have indicated in the last progress report, we were having difficulty producing single crystal Bismuth films. In December of 1967 the Principal Investigator visited Mr. Arthur R. Clawson at the Naval Weapons Center in Corona, California. Mr. Clawson has had considerable experience in producing single crystal thin films, and the Principal Investigator discussed his procedure with him at length. Mr. Clawson was kind enough to give the Principal Investigator several samples of single thickness Bismuth films of approximately 5,000 Å thickness mounted on glass substrates.

We have conducted one experiment to measure the permittivity of these films. The frequency was 15 GHz and the Bismuth film was in a gas helium environment which in turn was immersed in liquid helium. We were unable to draw any quantitative conclusions from this experiment due to the fact that there were a number of system parameters whose temperature dependence we did not know with certainty. The most interesting aspect of this experiment was that we found that the single cavity resonance which was measured at room temperature degenerated into several closely spaced resonances when the temperature was lowered.

We are currently preparing a new experiment which will allow us to monitor precisely the way that the various parameters of the system change when the temperature is lowered. For example, a temperature sensor will be attached to the cavity so that we can monitor its temperature.

Also we are using an improved cavity in which we can remove the substrate and thin film from the cavity while the cavity is at liquid helium temperature. This will allow us to see precisely what effect the thin film has on the resonance frequency of the cavity. This cavity and the attached waveguide used to excite the cavity are shown in Fig. 1. The overall system including the liquid helium Dewar is shown in Fig. 2.

A proposal for continued support of this work has been pending with the Naval Electronics System Command since January 6, 1967. We have recently heard from this Command that they are now willing to fund this work. We are hopeful that a contract can be signed during May, 1968, and that funding can begin on June 1, 1968.

During the past six months one graduate student, Mr. Eric Rahneberg, has been doing the work of this Grant. He has been supported by the Department of Electrical Engineering. Mr. Rahneberg is working toward the Ph.D. degree.

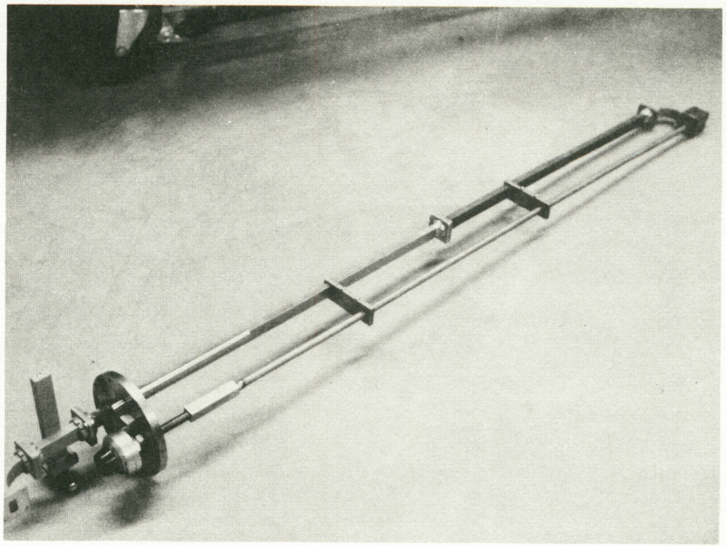


Figure 1

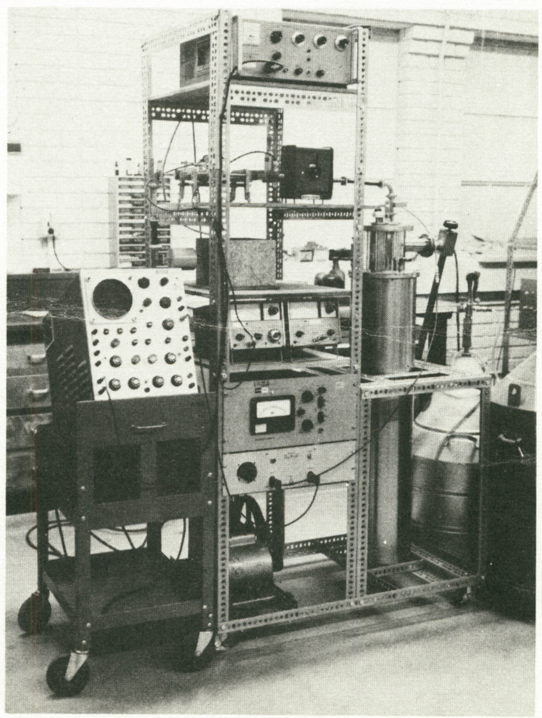


Figure 2

Grant Number 25.	November 12, 1966	$3,000
Grant Number 27.	March 9, 1967 (Additional support)	2,500

Investigator L. J. Demer, Professor
Department of Metallurgical Engineering

Title: Aid in Obtaining an Electron Microscope for the Study of Stacking Faults in Metal Systems

Summary:

This report covers two separate but related grants by the NASA Space Sciences Committee from funds supplied by the NASA Institutional Grant to the University of Arizona.

The relation between the two grants stems from the fact that the funds from both grants have been applied to the purchase of an electron microscope by the Department of Metallurgical Engineering. Purchase of this instrument is being made in connection with a research grant made to this Department by the National Science Foundation.

An Hitachi Perkin-Elmer HU-200 electron microscope was ordered about 15 March 1967. Initially, it was to be delivered in October 1967. The next date given for its arrival was sometime in November 1967. Modifications of certain portions of the equipment caused another delay until March 1968. Then it was to arrive in early April. Now it is indicated by the Perkin-Elmer Corporation that the HU-200E instrument will be shipped by air from Japan along with a similar instrument for the Oak Ridge National Laboratory, on or about May 10, 1968.

The Perkin-Elmer Corporation, through its representative Mr. Robert H. Davis, has reported that an improved resolution specification has been one of the reasons for a delay in delivery. Several other improvements have been added to the specifications on these two grants:

1. A 50 KV tap for use with a probe accessory.
2. 4.5 A resolution.
3. A new type filament and cathode for longer filament life and better efficiency.
4. A longer high voltage cable up to 22 feet may be used.
5. Continuous use at 200 KV for eight hours is guaranteed.

An electron micrograph received from Hitachi via Perkin-Elmer or a specimen of K_2PtCl4 and K_2PtCl6 6aken under direct magnification of K123,000 and with an enlarged magnification to X1,230,000 at an accelerating voltage of 200 KV on an HU-200E instrument demonstrates a pattern showing a resolution of 3.5 A. This is far better than the originally specified value of 10 A resolution.

The work of these two grants of aid in obtaining an electron microscope will have been completed upon arrival of the electron microscope. Actually, the funds were completely expended or comitted upon the writing of the purchase order for the instrument in March 1967.

Although the two NASA grants were not instrumental in helping to obtain the NSF grant for research using the electron microscope, for the NSF grant predated the award of the NASA grants, still the $5,500 total of the latter grants was a vital factor in realizing the necessary sum to purchase a 200 KV instrument which will be one of the two first such instruments put to use in this country. Thus, the NASA grants assisted the Metallurgical Engineering Department of the University of Arizona in obtaining a very special instrument for research and instruction which should prove of great value in local research programs and which actually represents a unique facility for research in the structure of materials.

The presence of the electron microscope will provide an experimental facility for carrying out the proposed work on the NSF research grant mentioned above. The proposed work in the NSF grant is divided into three parts. The first involves a study of the temperature dependence of the stacking fault energy in metal systems. The second area is concerned with interstitial induced ordering in the Fe-Cr-Ni system (austenitic stainless steels). The third research area of the proposal is concerned with the zone locking and serrated yielding of precipitation-hardening aluminum alloys. Use of transmission electron microscopy has been proposed as the major research tool in each of these three areas of research proposed for the NSF work.

Since no other electron microscope capable of transmission microscopy in metal foils is available for use by the members of the Metallurgical Engineering group, the presence of the new instrument is a necessity for carrying out the details of the proposed work. The importance of the NASA grants of financial assistance is thus clear. It may be added that the sum contributed by the two NASA grants amounts to less than 10% of the total required to purchase the HU-200 instrument, yet in a plan of financing which called upon ten separate sources of funds to realize the total required amount, each contribution is very important.

Over succeeding years the presence of the electron microscope instrument should be of much assistance in the Masters and Doctoral investigations of many students in the Metallurgical Engineering and other Departments of the University whose students available themselves of the special characteristics of the 200 KV instrument. The contribution of the two NASA grants will clearly be of continuing assistance. One student is completing his M.S. thesis in connection with the project on Stacking Faults in Metal Systems. He is employing X-ray diffraction techniques.

Grant Number 26. December 19, 1966 $27,615
(See also Grants Number 33 and 35)

Investigator Gerard P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: High-Altitude Infrared Spectroscopy Program

Summary:

This research project has been completed. Final Report was included in the third Semiannual Report.

Grant Number 27. March 9, 1967 $2,500
(See also Grant Number 25)

Investigator L. J. Demer, Professor
Department of Metallurgical Engineering

Title: Aid in Obtaining Electron Microscope for the Study of Stacking Faults in Metal Systems

Summary:

See Final Report for Grant Number 25.

Grant Number 28. March 1, 1967 $7,000
(See also Grant Number 57)

Investigator John O. Kessler, Professor
Department of Physics

Title: Research on Liquid Crystals

Summary:

The NASA support made available for this work was used for two overall purposes: (1) to aid in establishing a laboratory concerned with the thermal properties of liquid crystals in electric and magnetic fields, and (2) to aid in the performance of some specific experiments.

1. An apparatus for the accurate measurement of the (anisotropic) thermal conductivity of nematic liquid crystals has been constructed. The experimental method employs a magnetic field to determine the direction of the anisotropy. Parallel or perpendicular electric fields can also be applied.

The design of this apparatus is entirely novel. Quantitative measurements on the thermal conductivity in applied fields have not been made previously. The results are expected to be of great importance in the characterization of the liquid crystal phase. These experiments will constitute the thesis of at least one graduate student and will presumably produce several papers with NASA credits.

2. (a) We have performed quantitative measurements on the low frequency electrical properties of the liquid crystal substance most widely used in experiments. These measurements showed that previous interpretation of low frequency electrical properties in terms of ferroelectricity were erroneous. They also indicated the presence of a hysteretic ion conduction mechanism.

The results were published in "Molecular Crystals and Liquid Crystals".

(b) Some novel ideas on magnetic alignment of liquid crystals were worked out with the aid of this grant. They were presented at an American Chemical Society Symposium and published in the proceedings.

(c) Preliminary thermal conductivity experiments were performed. They not only were used to guide design of the apparatus mentioned in 1. but also showed that there exists no anomalous equilibrium magnetocaloric effect, as claimed in the literature. The results were accepted for publication in "Molecular Crystals and Liquid Crystals".

Publications:

1. J.O. Kessler and W.O. Rasmussen, "Non-linear Impedance of a PAA Capacitor", (Abstract), Second International Liquid Crystal Conference, Kent State, Ohio, 1968.
2. J.O. Kessler and M.T. Longley-Cook, "Heat Transport in Liquid Crystals", (Abstract), Third International Liquid Crystal Conference, Berlin, Germany, 1970.
3. J.O. Kessler, M.T. Longley-Cook, and W.O. Rasmussen, "Low Frequency Electrical Properties of p,p^{1}Azoxyanisole", *Molec. Crystals*, *8*, 327 (1969).
4. J.O. Kessler, "Magnetic Alignment of Nematic Liquid Crystals", Liquid Crystals and Ordered Fluids, Johnson and Porter, eds., Plenum Press, p. 361, 1970.
5. M.T. Longley-Cook and J.O. Kessler, "Heat Transport in Liquid Crystals", accepted for publication in "Molecular Crystals and Liquid Crystals".

Grant Number 29. April 1, 1967 $2,000

Investigator Gerard P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: Budget to Complete 16-inch Telescope for Tumamoc Hill

Summary:

This grant was requested for the completion of the 16-inch telescope for Tumamoc Hill. The telescope and dome were complete and ready for use except that some auxiliary installations in the dome were still needed to give access to the Newtonian focus where the photography was to be carried out. The investigators determined the most economical way of providing this access and found that a hydraulic scissor lift would be adequate. In addition, a shortwave radio was needed to receive the Bureau of Standards time signals, essential for precise astronomical positions. Finally, funds were needed for the telescope drive.

Work was completed and the telescope is in use by Dr. Elizabeth Roemer and Dr. G. Van Biesbroeck for observations of comets and asteroids. The telescope is also being used by graduate-assistant Dan Harris for visual observations of the moon.

Grant Number 30.

Investigator Alan B. Binder, Graduate Student
Lunar and Planetary Laboratory

This grant has been cancelled since Mr. Binder decided to leave the University. No money was expended.

Grant Number 31. May 1, 1967 $9,500

Investigator Neil D. Cox, Associate Professor
Department of Chemical Engineering

Title: Production of Zirconium in a Plasma

Summary:

The objective of this project is to refine essentially pure zirconia or zirconium tetrachloride to essentially pure zirconium in a radio-frequency plasma jet. This concept of a refining operation is being explored as a possible alternate to the presently used process, which utilizes magnesium reduction of $ZrCl_4$ vapor.

In the past six months, the radio-frequency generator was supplied with power from a 490-volt source. The design and construction of a reaction chamber, a ventilation hood, a power feeding system, a cold-finger probe, and a cooling water system was accomplished. The first experiment was conducted recently. Powdered $ZrCl_4$ was fed into the plasma. The product powder was collected on the cold finger which was placed in the plasma flame. The analysis of the product by X-ray diffraction showed that all of the $ZrCl_4$ had been changed to ZrO_2. This reaction was not entirely unexpected and was presumably the result of air leakage into the reaction chamber.

Work in the immediate future will be directed toward the reduction of air leakage to a minimal amount. The successful completion of this task will permit a realistic evaluation of Zr with yields of 5% or more which should provide sufficient basis for seeking additional support for constructing an air-tight recycling system.

As of September 1970 the work under this grant is still in progress. When sufficient data has been produced for final publication, support under this grant will be acknowledged and copies of publications will be submitted.

Grant Number 32. May 1, 1967 $2,490

Investigator Thomas Gehrels, Associate Professor
Lunar and Planetary Laboratory

Title: Proposal to the Space Sciences Committee for a Mounting and Shelter for Polarimetric Observation of the Whole Moon to be Made at Tumamoc

Summary:

A mounting and shelter were provided for polarimetric observation of the whole moon to be made at Tumamoc.

The equipment is in operation at Tumamoc and the first observations have been obtained of the brightness, colors, and polarization of the whole moon. The objective of the work is to obtain data for comparison of the moon with data obtained on Mercury, Mars, and other planets. The measurements on the moon, and on standard stars, are being made especially by Mr. S. F. Pellicori and Mr. C. KenKnight at selected phases of the moon.

Grant Number 33. May 15, 1967 $15,000
(See also Grants Number 26 and 35)

Investigator Gerard P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: Partial Funding of IR Interferometer

Summary:

The total amount of this grant has been expended for the purchase of the Interferometer which is being used both for ground-based and high-altitude programs. The results of these programs are covered in the Final Reports for Grants Number 26 and 35, submitted with the Third Semiannual Report.

Grant Number 34. May 15, 1967 $8,100

Investigator Stephen Jacobs, Professor
Optical Sciences

Title: Investigation of Laser Linewidth

Summary:

The objective of this project is to determine the fundamental spectral profile or linewidth of an ideal laser by measuring the power spectral density of the beat note between two independent free-running lasers.

To review the experiment, we are attempting to measure the fundamental linewidth of a laser, that is, the linewidth due to quantum fluctuations, rather than environmental perturbations. Previous attempts at measuring this linewidth have failed because of the latter effect, which masked the former. The method here used is to construct two gas lasers in nearly identical environments and to measure the beat, or difference frequency, by means of a spectrum analyzer. If one laser has a very narrow linewidth and the other a broad one, then the power frequency spectrum of the beam approaches closely the laser linewidth.

Professors Jacobs and J. Hanlon have constructed a pair of stable, He-Ne gas lasers from a single block of fused silica. Several modifications in the design have occurred since the previous report (See Figure 1 for original design).

1. In order to assure non-fluctuating polarization orientations a Brewster angle window assembly has been included.
2. The original method for gross adjustment of laser length via buildup of evaporated gold has been replaced by a controllable but permanently sealable gas pressure tuning cell. (See Figure 2). The

decision not to rely on the gold buildup was based on the fact that the available evaporation facility is heavily committed to many projects and our method entailed tieing up that equipment for a week or two.

The present plan calls for gas pressure tuning to bring the first laser into oscillation and then a similar operation to bring the second laser into oscillation at a frequency near that of the first. Fine tuning is achievable by means of heating coils shown in Figures 1 and 2.

3. The beam combining interferometer shown in Figure 1 has been tentatively replaced by a simpler scheme (See Figure 2) which has the advantage that it is adjustable, almost as stable, and does not entail the unequal beam division (95%-5%) encountered with the first design. The new interferometer is made of low-absorption CaF_2 which is accurately plane parallel. With the new design, vibration of the beamsplitter causes no differential doppler shifting of the two beams corresponding to translations. Only twist motion of the beamsplitter introduces spurious doppler frequency shifts, and these should be least readily apparent in the beamsplitter structure.

Two experimental setbacks have been encountered: (1) As the finished assembly was being prepared for filling with gas, an accidental breakage occurred which has entailed about six weeks' delay. (2) The CaF_2 beamsplitter was originally polished flat and parallel by the Harshaw Chemical Company. Since the parallelism they provided was not good enough, further polishing was called for, during which the CaF_2 began to cleave internally. There is still some hope that the cleaved region can be ground away, in which case the beamsplitter can be completed. Otherwise a new piece of CaF_2 must be purchased.

Publications:

Hanlon, J. and Jacobs, S.F., "Narrowband Optical Heterodyne Detection", paper presented at Conference on Laser Engineering and Applications, June 7, 1967, Washington, D.C.

Hanlon, J. and Jacobs, S.F., "Narrowband Optical Heterodyne Detection", Applied Optics, Vol. 6, 577, 1967

Figure 1

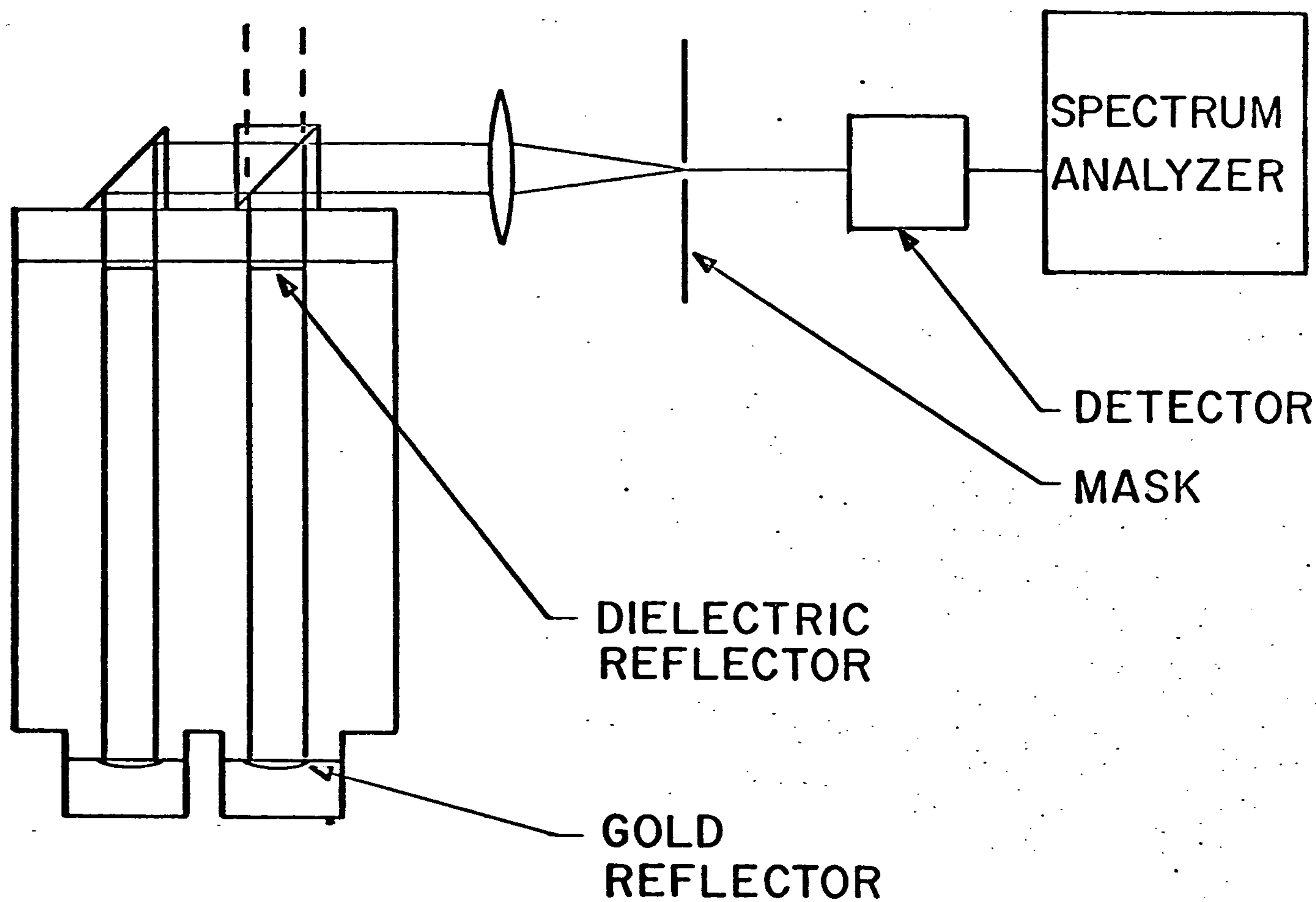
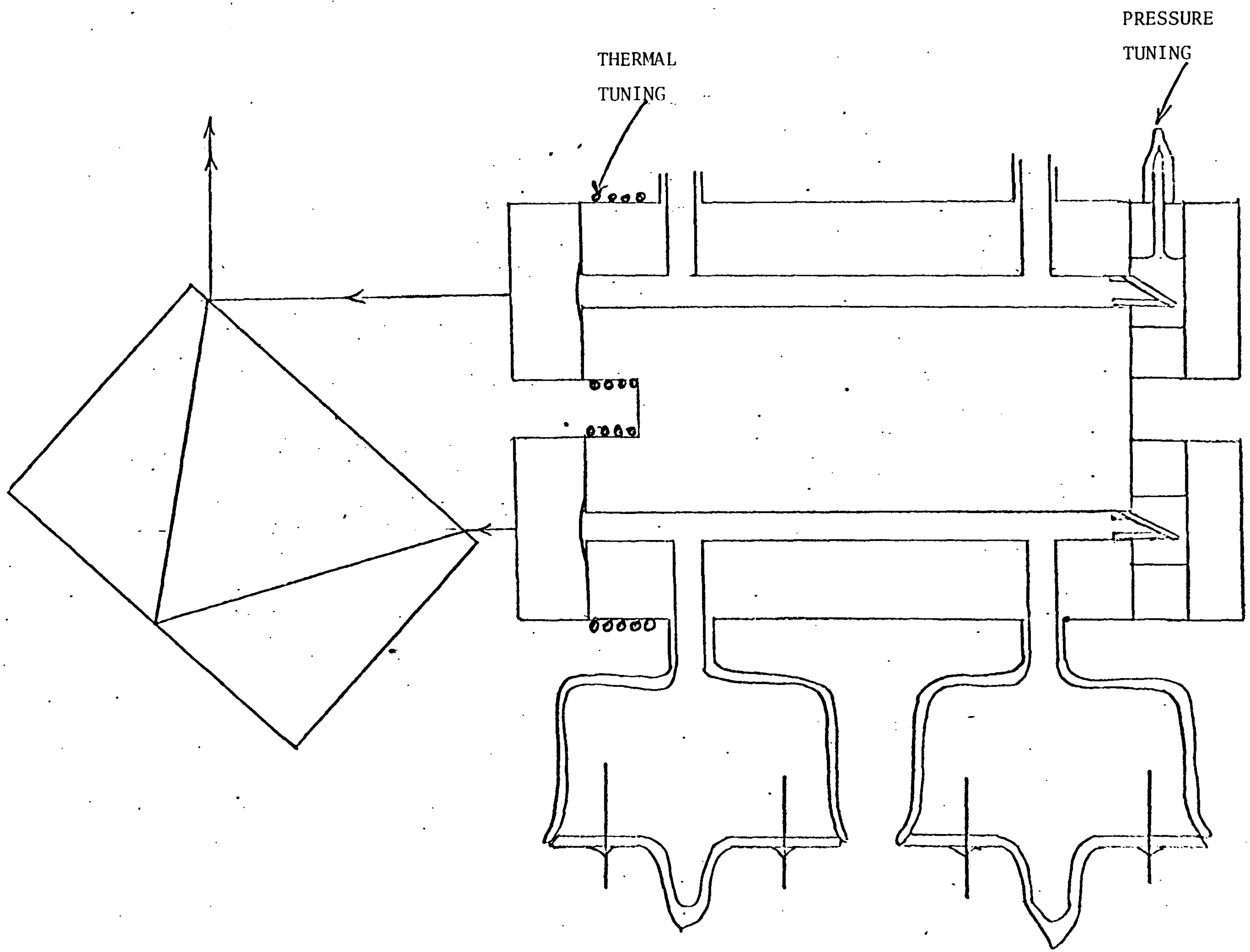

SPECTRUM
ANALYZER
DETECTOR
MASK
DIELECTRIC
REFLECTOR
GOLD
REFLECTOR

Figure 2



Grant Number 35. July 7, 1967 $49,750

Investigator Gerard P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: Solar, Lunar, Planetary, and Stellar Spectroscopy, 1-1000μ

Summary:

This research project has been completed. Final Report was submitted with the third Semiannual Report.

Publications:

The following LPL Communications were in part the result from research carried out under this Grant, as well as Grants Number 26 and 33:

No. 93 Kuiper, G.P., Forbes, F.F., and Johnson, H.L., "A Program of Astronomical Infrared Spectroscopy from Aircraft"

No. 94 Kuiper, G.P., and Steinmetz, D.L., "Solar Comparison Spectra, 1.0-2.5 μ from Altitudes 1.5-12.5 km"

No. 95 Kuiper, G.P., and Forbes, F.F., "High Altitude Spectra from NASA CV-990 Jet. I. Venus 1-2.5 Microns, Resolution 20 cm^{-1}"

No. 96 Kuiper, G.P., and Cruikshank, D.P., "Calibration of Weak 1.4 and 1.9 μ H_2O Absorptions"

No. 97 Cruikshank, D.P. and Kuiper, G.P., "Sulfur Compounds in the Atmosphere of Venus. I. An Upper Limit for the Abundance of SO_2"

No. 98 Cruikshank, D.P., "Sulfur Compounds in the Atmosphere of Venus. II. Upper Limits for the Abundance of COS and H_2S"

No. 99 Kuiper, G.P., Sill, G.T., and Cruikshank, D.P., "The Near-Infrared Spectrum of Carbon Suboxide. I. Region 1-2.5 Microns"

No. 100 Kuiper, G.P., Forbes, F.F., Steinmetz, D.L., and Mitchell, R.I., "High Altitude Spectra from NASA CV-990 Jet. II. Water Vapor on Venus"

No. 101 Kuiper, G.P., "Identification of Venus Cloud Cover" (No reprints available)

No. 123 Kuiper, G.P. and Cruikshank, D.P., "Arizona-NASA Atlas of Infrared Solar Spectrum - a Preliminary Report"

No. 124 Kuiper, G.P., Cruikshank, D.P. and Bijl, L.A., "Arizona-NASA Atlas of Infrared Solar Spectrum. Report II"

No. 125 Kuiper, G.P., "Arizona-NASA Atlas of Infrared Solar Spectrum. Report III"

No. 160 Bijl, L.A., Kuiper, G.P. and Cruikshank, D.P., "Arizona-NASA Atlas of Infrared Solar Spectrum, Report IV"

No. 161 Bijl, L.A., Kuiper, G.P., and Cruikshank, D.P., "Arizona-NASA Atlas of Infrared Solar Spectrum, Report V"

No. 162 Kuiper, G.P., Thomson, A.B., Bijl, L.A. and Benner, D.C., "Arizona-NASA Atlas of Infrared Solar Spectrum, Report VI"

No. 163 Bijl, L.A., Kuiper, G.P. and Cruikshank, D.P., "Arizona-NASA Atlas of the Infrared Solar Spectrum, Report VII"

No. 164 Bijl, L.A., Kuiper, G.P., and Cruikshank, D.P., "Arizona-NASA Atlas of the Infrared Solar Spectrum, Report VIII"

No. 165 Bijl, L.A., Kuiper, G.P., and Cruikshank, D.P., "Arizona-NASA Atlas of the Infrared Solar Spectrum, Report IX"

Grant Number 36. July 13, 1967 $12,940

Principal Investigator Granino A. Korn
Department of Electrical Engineering

Title: Purchase of a Dual DEC Tape Unit and Control for PDP-9 Data Processor

Summary:

The PDP-9 Electrical Engineering Department DECTape unit purchased under this grant has been installed and tested. Both hardware and software are working nicely.

The DECtape system, which takes the place of an expensive mass-storage system (such as a disk memory) for small digital computers, has made it possible to operate the PDP-9 with a keyboard monitor system; frequently used programs, such as the PDP-9 MACO assembler, the FORTRAN compiler, and a large subroutine library are stored on a system tape and are called simply by keyboard commands. This completely eliminates the awkward and slow loading of such programs with punched paper tape and permits very smooth man-machine interaction.

The availability of the DECtape/keyboard-monitor combination, in conjunction with our new homemade graphic-display console (also partly supported by a NASA institutional grant) has made it practical to apply for an NSF grant covering a major study of all digital simulation of dynamical systems. This grant, which will support five M.S. and Ph.D. students for two years, was funded by NSF in February 1968.

Institutional grant money could hardly have been spent in a more fruitful manner: the new DECtape unit makes operations more convenient and faster whenever the digital processor is used. Nevertheless, our earlier appropriations were barely enough to purchase the digital processor and would not have permitted us to buy the DECtape.

Grant Number 37. July 13, 1967 $27,150

Investigators: Donald J. Taylor, Assistant Professor, Co-Principal Investigator
B. E. Westerlund, Professor, Co-Principal Investigator
Ray J. Weymann, Professor R. L. Hilliard, Professor
Department of Astronomy R. E. Williams, Professor

Title: Development and Application of High Speed Area Scanning and Spectral Scanning Techniques

Summary:

The objectives of this research project were to develop equipment and techniques for scanning astronomical telescope images and spectra in a high speed repetitive fashion which averages out (a) intensity modulations due to seeing, scintillation, and atmospheric transparency, and (b) sky background fluctuations. These techniques were then to be applied to the following diversified astronomical problems:

1. A search for underlying galaxies associated with quasars 3C 273 and Ton 256.

2. Planetary limb darkening and spectrum scans in monochromatic light to study the heat balances of the planets.

3. Image scans of planetary nebulae to study their ionization structure.

4. Image scans of bright rim structures in diffuse nebulae to study the evolution of diffuse nebulae and shed light on the problem of star formation.

5. Image scans of Elliptical galaxies to study the distribution and rotation of interstellar gas as revealed by the OIIλ3727 line to check dynamical models of these galaxies.

6. Image scans of spiral galaxies in spectral ranges which make possible the detection of certain types of objects such as Wolf Rayet stars in these galaxies.

7. Detection of circumstellar envelopes around red giant stars by image scans made in very narrow spectral band passes to study the mass ejection mechanism.

8. Detection of emission nebulae around novae and structure and variation of these nebulae by image scanning.

9. Studies of seeing disc intensity distributions using the by-product image scans of stars made for comparison purposes during the observations described above.

I. Development of Equipment and Techniques:

Originally we intended to build a two-channel area scanner capable of scanning both an astronomical object and a comparison star at the same time. The unexpected termination of the grant took away the funds for the second channel. Our observational experience has confirmed the absolute necessity of having a second channel to monitor the seeing disc simultaneously when observations are being attempted which depend on small differences in the seeing disc structure.

The single channel area scanner which was built consists of a slit driven back and forth in the focal plane by an AR-4 loudspeaker motor servo controlled by a Pickering 7306 (DC to DC) linear differential voltage transformer (LDVT) to follow a triangular waveform from an Exact 504 function generator. The error signal is amplified by a Zel-1 operational amplifier followed by a Hewlett Packard 6824A power amplifier which drives the loudspeaker motor.

The scanner has an adjustable peak to peak amplitude of up to 12 mm. The scan is linear in the distance vs time relationship to $\pm$ 3μ ($\pm$ 1/30 sec of arc with the Steward Observatory 90-inch telescope) at 1 Hz scanning frequencies. It works well at frequencies up to about 10 Hz (linear to 5μ); above that linearity and amplitude capabilities are progressively degraded due to the 10 millisecond settling time at turnaround.

Scanning apertures are mounted on interchangeable dovetail slides. The apertures used range from 60μ to 500 μ in diameter and 36μ x 500μ to 100μ x 1000μ slits. The mechanical construction of the area scanner consists of a 6-3/4 inch long, 1/8 inch diameter, ground steel rod with the loudspeaker voice coil cemented to a disc at one end and the aperture holder at the other end. The rod slides through two oilite sleeve bearings and is constrained from rotation by a parallel "outrigger" rod sliding through a third oilite sleeve bearing. The LDVT armature is mounted parallel to the rod opposite the outrigger. There are no springs in the system, which simplifies response optimization since the system is nonresonant.

Compared to the cam driven area scanners developed at Lowell Observatory, this design has the advantage that no expensive high precision cam machining is required and of continuously adjustable scan amplitude, frequency, and wave form.

The area scanner is followed by either a UBV filter module, or a monochromator module which permits coverage from 0.1-1.2μ in wavelength by using S-13, S-20, and S-1 photomultipliers.

The filter module has a wheel holding up to six 1x1 inch filters. The wheel is turned either manually or with a stepper motor which permits cycling through filters in phase with the area scan. In this way for example UBV scans can be interlaced.

With the monochromator a Jarrell Ash 1/4 meter model having back to back interchangeable visible and infrared gratings, available bandpasses range from 300 to 3Å. For spectrum scanning the monochromator grating is driven by a stepper motor.

The wavelength stepper has several modes of operation. First there is a rapid scanning mode intended for partly cloudy nights, in which the stepper simply drives the grating back and forth over the desired wavelength region as rapidly as it can. Our experience has shown that averaging many rapid scans indeed averages out the effects of clouds on relative-energy distributions. Cloud absorption is evidently truly gray.

The other main mode consists of stepping to evenly spaced wavelengths, stopping at each wavelength to count photons, then after the last wavelength flying back rapidly to the beginning to repeat the process. The advantage of this mode is that the counts in each CAT channel (see below) pertain to a fixed wavelength bandpass. The bandpass is not broadened by scanning during counting as with the rapid mode.

Finally with the step and stop mode the area scanner can be driven to chop between sky and star on alternate CAT channels so that the sky counts are interlaced in channels with the sky plus star counts.

The photomultiplier photon pulses are fed to a pulse amplifier and discriminator with 10 MHz speed designed and built as part of this research. They are then counted in a Computer of Average Transients (CAT) 400C signal averager having 400 channels. The channels represent scan distance (or wavelength for spectrum scanning). The average of a number of scans (typically 50 to 400 scans) is then recorded on a Digi Data DSR 1430 digital magnetic tape recorder for further processing with the university computer.

II. Research Results on the Specific Astronomical Problems:

Problems listed as #4, 5, and 8 in the beginning were the specific interest of one of the co-principal investigators, Dr. Bengt Westerlund. He left the University of Arizona to assume directorship of the European Southern Observatory in Chile before the area scanner was ready.

As often happens the most significant result from this program was not one of the original intentions. It was the discovery of the first (and to this date only) optical pulsar, NP0532 in the Crab nebula (Cocke, Disney and Taylor, 1969). The discovery of this optical pulsar was a decisive factor in our present picture of the pulsars as neutron star remnants of supernovae radiating their kinetic energy of rotation by some means utilizing their intense magnetic fields. Pulsars had not even been discovered when the proposal leading to this grant was written. It was the electronics assembled for area scanning by means of this grant which was used to make the discovery. It was ideal for this purpose because the intended area scanning frequencies of 30-1Hz match the pulsar frequencies. Following the discovery the equipment was used in conjunction with the polarimeter of Dr. Tom Gehrels to measure the linear and circular polarization of NP0532 (Cocke, Disney and Gehrels, 1969).

The delay in completion of the Steward Observatory 90-inch telescope delayed the initiation of the area scanning observing programs until October 1969. Earlier attempts to utilize the Lunar and Planetary Lab 61-inch telescope were not completely satisfactory due to the coarse (for our purposes), discrete, 1" step nature of the setting and guiding motions of that telescope.

(1) As a result our search for underlying galaxies associated with quasars had evolved into an attempt to detect spectral features from stellar content in the faint outer regions around 3C 120. Sky-object chopped spectrum scans were made. With a 200 Å bandpass scans showing a spectrum for the regions having only 1/6 the sky intensity were successfully obtained. However when the bandpass was reduced to the 16 Å needed to detect stellar spectral features the signal was very weak and no stellar features were definitely detected. We would still like to try area scanning Ton 256 and 3C 273 to look for enhancements in the wings of the seeing disc due to any surrounding galaxy, but it is now clear that this requires the two channels we had originally planned on.

(2) Planetary limb darkening: Limb darkening area scans were made of Jupiter from 0.1-1.0μ using a 0.6 sec of arc diaphragm. The data is not yet completely reduced and analyzed. The data treatment is complicated by the belts and detail of the planetary disc. Preliminary results show a surprisingly strong color dependence in the blue for the equatorial zone with about

twice the color gradient shown by other features. The first values obtained for limb darkening coefficients appear to be in rough agreement with earlier published results.

(3) Studies of seeing disc intensity distributions: Preliminary results from seeing disc area scans show the following characteristics:

a. The seeing disc size can vary by about a factor of two from minute to minute. The usual behavior consists of a few ($\lesssim$10) minutes of relatively stable average size followed by an abrupt transition to some new average which is again stable for a few minutes and so on. The seeing disc size generally encountered ranges from about 1" to 2" diameter. These abrupt changes are what makes 2 channels mandatory if it is important to know the seeing disc for comparison purposes.

b. There is no noticeable (ie.$\gtrsim$ .03") color dependence of the seeing disc size.

c. For separations of up to at least 7° (near the zenith) there is no noticeable (>.1") difference in seeing disc size. Thus it does not appear essential to have a comparison star very near an object in order to have the same average seeing disc characteristics.

d. The zenith distance effect on a 1" seeing disc in going from 1.0 to 1.9 A.M. is only of the order of 0.4" arc.

Programs #3, 5, and 7 have not been started yet. In the case of #3, "image scans of planetary nebulae to study their ionization structure", Williams has been using photography with image tube and interference filter. Due to the higher efficiency and resolution of this approach the main value of area scanning for future use on this problem appears to be for absolute calibration of the image tube technique.

Other Programs:

There are two other programs not listed in the proposal which were undertaken with the equipment.

The first was area scanning the nuclei of galaxies M-31, M-32, NGC 3379, 4472, 4594, 4697, 3115, 4621 to look for an enhancement of CN absorption toward the center. This work undertaken with Dr. Hyron Spinrad of the University of California is an extension of his work done with 10" resolution to 5 and 2" resolution. The reduction is just being completed. The early results are that flattened systems show a higher CN index in the center and index gradient at the center.

The second program was a search for interstellar absorption due to γ-Fe_2O_3 in the λ4000 region as predicted by Dr. Donald Huffman. This was done by spectral scanning stars having strong interstellar λ4430 absorption which Dr. Huffman claims is also due to γ-Fe_2O_3. The results for a half dozen stars were negative, although a weak absorption might be present lost in blends of other weak lines. The main difficulty is in finding a closely enough matched in spectral type unreddened comparison star. Existing spectral classifications do not seem to be precise enough.

The area scanner was used to scan across the nucleus of the Seyfert galaxy NGC 4151 in the near infrared (between the I and J bands). These observations were made for Dr. Andrezj Pacholczyk to see if there were other strong sources near the nucleus which could cause apparent variability due to their inclusion or exclusion from a photometer diaphragm. No other sources were found.

Other Users:

The spectrum scanner has been used by Dr. Ed Schmidt for the observation of classical Cepheid variable stars and non variable yellow giants and supergiants. From these observations energy distributions will be derived which will be used to obtain the temperatures of these stars and a measure of the effect of line blocking on their colors. For the variables monochromatic light curves will be derived which are then to be employed in determining the radii of the stars.

Dr. Danielle Alloin of the Paris Observatory used the spectrum scanner to spectrum scan galaxies.

Final Remarks:

a. Conclusions: The area/spectrum scanner is a very flexible instrument which makes possible the solution of certain special astronomical problems where photoelectric linearity and dynamic range are needed for image photometry.

Because only one picture element is observed at any one moment it will probably eventually be surpassed by television like techniques now under development.

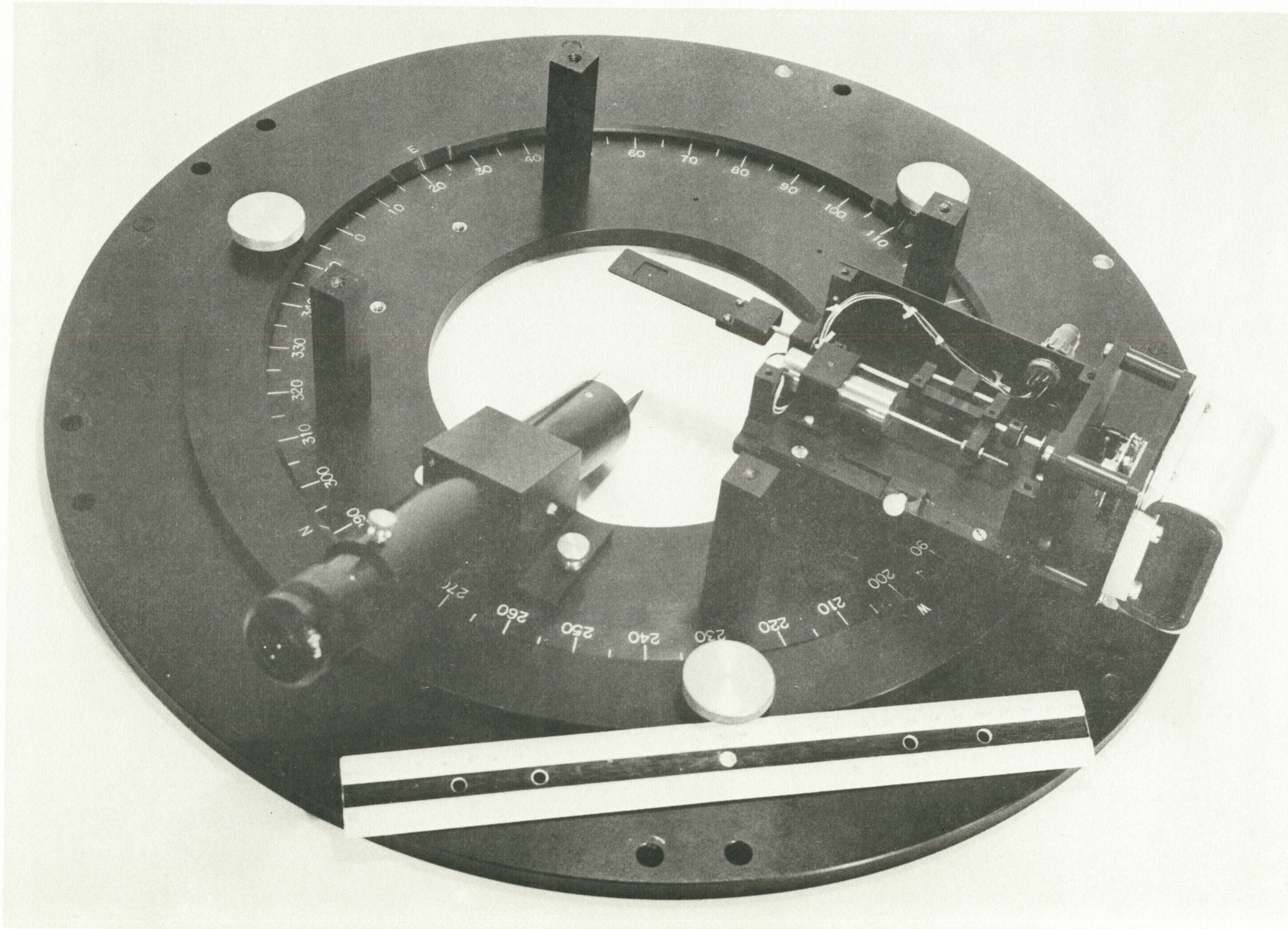
With two channels for area scanning so that the seeing disc can be simultaneously monitored it may be feasible to deconvolve the seeing disc from area scans of small angular diameter sources such as satellites, Pluto, and 3C273.

b. Publications: Because the 90-inch telescope has only been in operation this past year the results have not yet been published except for the pulsar observations (which were made with our 36-inch telescope and the LPL 61-inch).

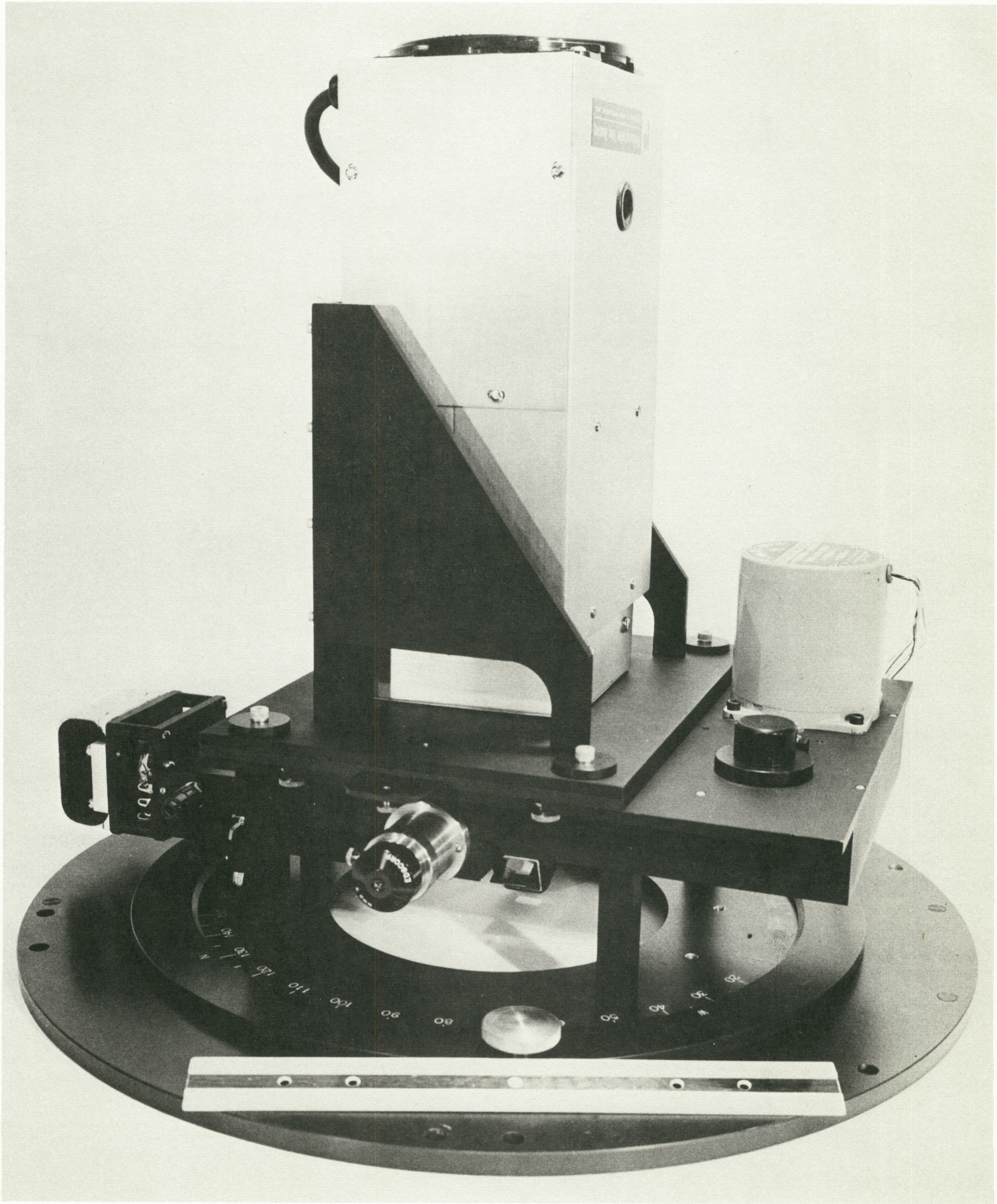
The results of the Jupiter limb darkening and CN absorption in the nuclei of galaxies, as well as a description of the instrumentation, should be published within the next year.

W. J. Cocke, M. J. Disney, D. J. Taylor, "Discovery of Optical Signals from Pulsar NP 0532", Nature, Vol. 221, 525-527, Feb. 8, 1969

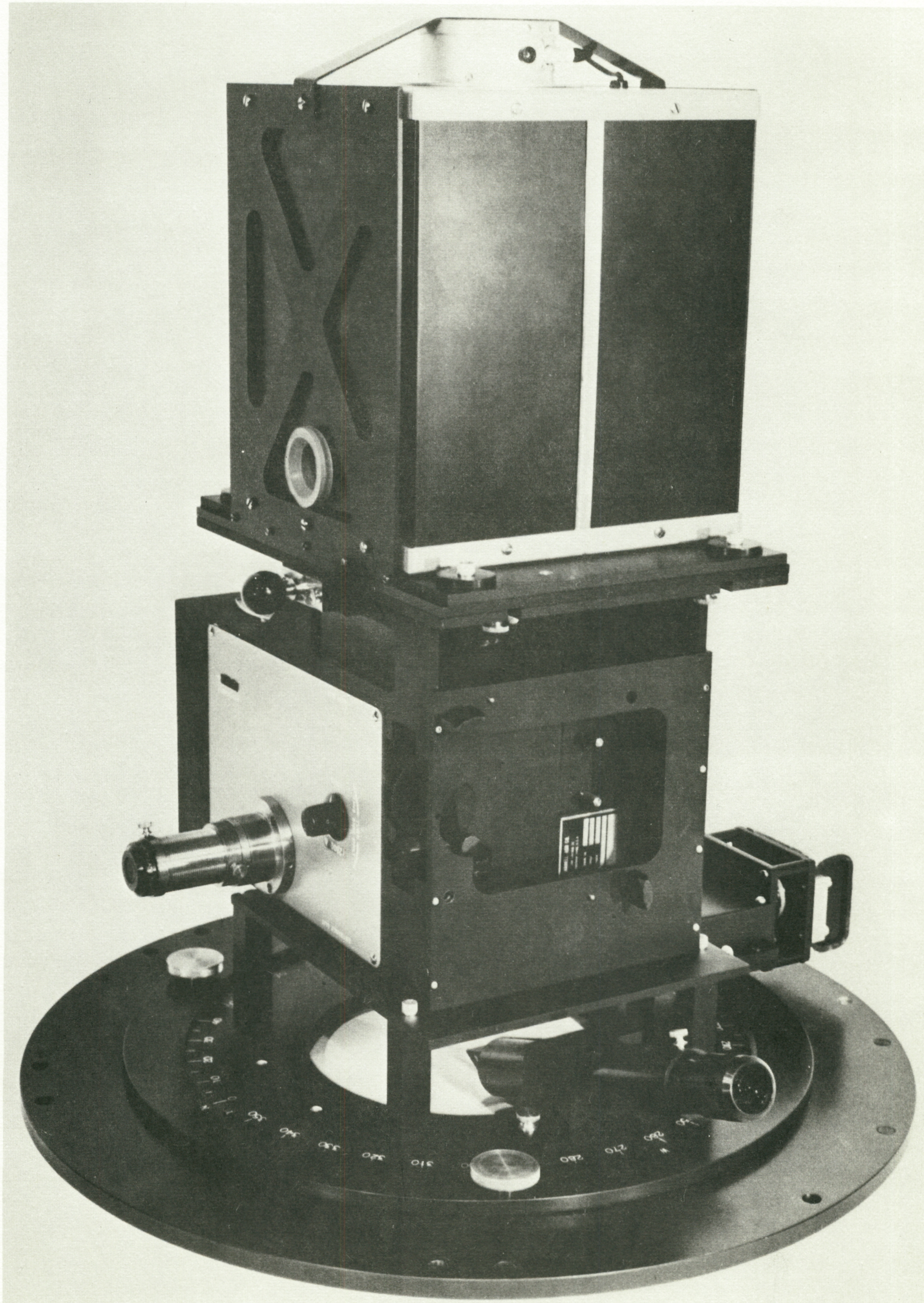
W. J. Cocke, M. J. Disney, T. Gehrels, "Optical Polarization Measurements of Pulsar NP 0532", Nature, Vol. 223, 576-578, August 9, 1969



Area Scan Aperture Driver (cover off), and Reflective
Guide Eyepiece, on Position Angle Circle



Area Scanner, with Filter Module, and Thermo-
electrically Cooled Photomultiplier Housing



Area scanner, with Monochromator Module, with Dry
Ice Cooled Photomultiplier Housing (for Infrared)

Grant Number 38. July 13, 1967 $7,650

Investigator: Monte V. Davis, Professor
Department of Nuclear Engineering

Title: Investigation of the Effects of Environment on the High Temperature Metal Oxides and on the Interaction at Interfaces between Metal Oxides and Refractory Metals

Summary:

The attempts to develop a high-temperature ceramic-to-metal seal which could be thermally cycled and which would operate at temperatures in excess of 1000° Kelvin were only partially successful. The basic approach was to use a high-temperature braze between a refractory metal and the metal oxide. The purpose of this braze was to wet the metal and interact with the metal oxide in such a fashion that there would be a graded oxygen-to-metal interface.

The basic materials used in this investigation were Al_2O_3 as the metal oxide insulator and either niobium or tantalum as the refractory metal material. The geometry of the test section is Shown in Fig. 1. The concentric cylinders are amenable to the geometry of the induction furnace and allows a layer of foil material to be placed between the cylinders to form the braze interface.

The assembled components for the ceramic metal seal were mechanically cleaned then given an alcohol and distilled water rinse. The assembled components were then placed in position in the induction heater inside a tubular vacuum system which was maintained at approximately 0.1 Torr of pressure. The samples were gradually brought up to the braze temperature in order that out-gassing would be complete. The sample then was brought to temperature required to melt the braze and was then held at this temperature until the braze could be seen to wet the alumina surface. It was then timed for approximately one minute and gradually reduced in temperature until the system

could be opened to the air, approximately twenty minutes after the brazing action was completed. A tantalum-titanium-alumina system or a niobium-titanium-alumina system formed seals which were vacuum tight under these conditions. The alloy of the titanium with the different refractory metals led to an extremely brittle bond but one that maintained its integrity through mild thermal cycling for many cycles. In Fig. 2 the interface is shown for the tantalum-titanium-alumina system after 30 cycles from ambient temperature to 1000° Kelvin with a cycle time of approximately fifteen minutes in a vacuum environment. As is seen in the photomicrographs, there is a sharp line of alloy formed between the tantalum and the titanium and a large amount of diffusion between the oxide and the titanium braze layer. A lack of success in the three-element seal led to adoption of seals which were fabricated using procedures outlined in the literature and based on the vanadium braze technique.

The vacuum brazing of refractory materials using a titanium braze has been shown to be a very successful high vacuum braze which will operate to temperatures in excess of 2000° Kelvin for extended periods if the time of operation at these temperatures is limited to periods under 100 hours. For long periods of time, Kirkendall Effects lead to a failure of the braze point and subsequent failure of vacuum components.

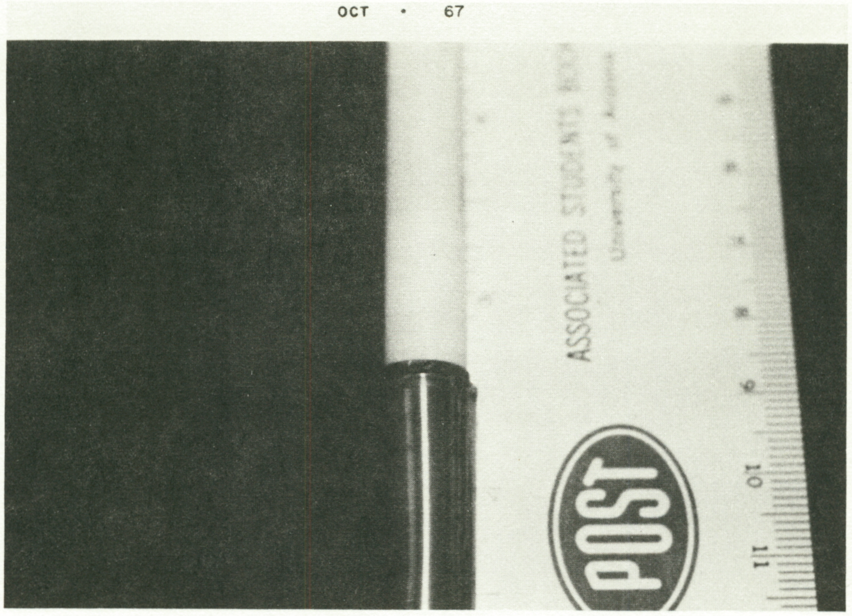


Figure 1

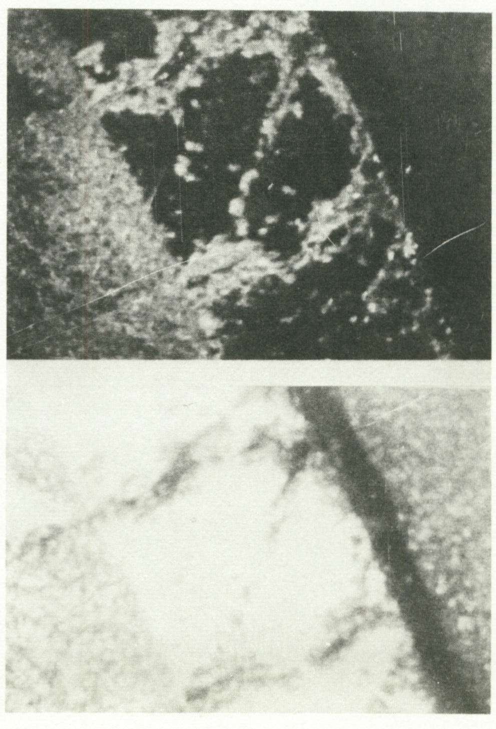


Figure 2

Grant Number 39. July 7, 1967 $1,010
(See also Grant Number 12)

Investigator Cecil A. Rogers, Assistant Professor
Department of Psychology

Title: Interim Funds for Skilled Motor Responses

Summary:

The basic objective of this study was to produce experimental conditions conducive to short-term forgetting of a skilled motor response; this was an effort to bridge the gap between traditional laboratory findings of consistent perfect motor retention and the applied situation finding of imperfect motor performance. A corollary goal was the partial resolution of methodological problems involved in measuring motor vs. verbal information processing capabilities.

The following students have worked in the laboratory on related topics in the field of human information-processing capabilities and received degrees either in June or August of 1968 as indicated:

A. John Hebert, Ph.D.
B. JoAnn Clawson Sanders, Ph.D.
C. Lee Brown, M.A.
D. David Allen, Ph.D.
E. Pamela Talley, Ph.D.

In all cases moderate research support was provided via use of equipment, facilities, and technicians. Additionally, their research was instrumental in obtaining support by fellowships provided by USPHS for Mr. Allen, by NASA for Mr. Hebert and Miss Talley.

An examination of warm-up, the second facet of motor forgetting, constituted a part of Mr. Brown's thesis. Data analysis and write-up of articles dealing with verbal-motor, pure vs. applied research and methodology in human memory and performance are in progress. Other projects underway in

this lab deal with human coding processes and techniques to promote retention (e.g. mnemonic devices). Outside support for continuation of work is pending. Publications:

Hebert, J., "Central-tendency Effect in the Generalization of a Voluntary Response", paper presented at symposium on stimulus equivalence sponsored by Western Psychological Association, San Diego, April 1968.

Wilson, G. and Allen, D. "Visual Evoked Cortical Potentials and Reaction Time as a Function of Onset", presented at Western EEG Society, Park City, Utah, February 1968. Published in Journal of Electroenecephalography and Clinical Neurophysiology.

Fox, W.L. and Rogers, C.A., "Forgetting of a Simple Motor Task", Psychonomic Science, 1966.

Rogers, C.A., "Human Learning and Retention", Contemporary Experimental Psychology, G.S. Reynolds (ed.), Glenview, Illinois.

Rogers, C.A., "On Assessing Verbal Stimulus Hierarchies", Behavioral Research Methods and Instruments, 1968.

Rogers, C.A., "Comments on Stimulus Equivalence", paper presented at symposium on stimulus equivalence, Western Psychological Association, San Diego, April 1968.

Grant Number 40. October 14, 1967 $900.00

Principal Investigator S. A. Hoenig, Professor
Department of Electrical Engineering

Title: Financial Support from the NASA Institutional Grant to Purchase a Lathe

Summary:

Funds were requested to purchase a Lathe to be used in support of research efforts in the Field Emission and Space Systems Laboratory.

This lathe has materially facilitated our research activity. It has allowed us to manufacture small parts more expediently and economically.

Grant Number 41. October 14, 1967 $5,896

Investigators John Poulos, Research Specialist
Dean B. McKenney, Research Specialist
Optical Science

Title: Support for Proposed Vacuum Evaporating Unit

Summary:

The purpose of this grant was to help in the purchase of a vacuum evaporating unit as an addition to the Optical Sciences Center Coating Facility to provide a more rapid source of specialized optical coatings primarily for space related research at the University of Arizona. This equipment is being used to produce thin films used by various NASA and Space Sciences related groups of the University.

The grant money was made available October 1967 and the equipment arrived at the University of Arizona in February 1968.

The following thin films have been made by Mr. Poulos, using an O.S.C. Bendix Balzers evaporation unit and are representative of the type of work which will be forthcoming for NASA related groups at the University:

Beam Splitters:	Dielectric- 50/50 at .9500μ	Dr. R. Shack	O.S.C.
	Dielectric- 50/50 at 3.39μ	Dr. S. Jacobs	O.S.C.
Spike Filters:	Multilayers 80% Transmission 40 A° halfwidth	R. Cromwell	S.O.
Laser Coatings:	Multilayers 99.8 Reflectivity visible to 5μ	Dr. S. Jacobs	O.S.C.
Mirrors:	10" & 12"	Dr. Forbes	L.P.L.
	6", 8", & 10"	Dr. B. Tifft	S.A.
		Dr. R. Hillard	S.O.
Anti-Reflection (Germanium)	2μ & 10.6μ	Dr. F. Low	L.P.L.

Grant Number 42. October 13, 1967 $4,000

Principal Investigators John A. Reagan and Benjamin M. Herman
Institute of Atmospheric Physics

Title: Partial Support in Initiating a Lidar Probing Study

Summary:

The purpose of this project is to initiate a lidar atmospheric probing program. The NASA Institutional Grant has been used to purchase initial equipment necessary to initiate the program prior to expected contract support from the National Science Foundation.

The entire NASA Institutional Grant funds have been expended for purchasing of certain required equipment for the lidar system (Pockels cell, Q-switch, and associated electronics).

A proposal has been prepared and submitted to NSF for continued support of this work.

One theoretical paper is currently being completed and will be submitted for publication in the near future.

An analysis of the requirements of the experimental system has been completed, and the laser system has been purchased. Preliminary design of the overall lidar system has been completed.

Five graduate students are currently working on this project. It is anticipated that theses requirements for these students will be met from work performed on this project.

Grant Number 43. October 13, 1967 $2,000

Principal Investigator Lee B. Jones, Assistant Professor
Department of Chemistry

Title: The Mechanism of Photochemical Reactions

Summary:

See Grant Number 5 for Final Report.

Grant Number 44. October 21, 1967/May 6, 1968 $5,500 + $300.25
(See also Grant Number 62)

Principal Investigator Keaton Keller, Professor
Department of Nuclear Engineering

Title: Proton Scattering Microscope

Summary:

A Nelson Proton Scattering Microscope is being constructed which can be used to examine the surface structure of crystals faster and in some ways better than any other current method. In fact, this instrument can give information about the surface structure from a few to hundreds of atom layers thick, that is practically impossible to obtain using X-rays and electron microscopy.

The items listed in the budget have been on order for some time and those called the vacuum system parts have arrived. Also, the main item, the proton source and lens system, arrived April 22, 1968. Although this custom-made proton accelerator section was on order from the High Voltage Engineering Corporation for about three months, it is expected that the target chamber and vacuum system can be built on it in less time than it would have taken us to develop and build it. All the electronic components are here and wiring of the control system is underway. At present the biggest problem is to obtain funds for a vacuum pump, and special viewing window. After these items are obtained the device can be completed and testing started, and we believe we could be ready for a research project in four or five weeks.

The Nuclear Engineering Department contributed about $2,500 worth of electronic equipment and about that much of vacuum equipment toward the construction of the proton scattering microscope.

Grant Number 45. November 4, 1967 $11,405

Investigators: Harold C. Fritts, Professor
Valmore C. LaMarche, Jr.
Laboratory of Tree-Ring Research

Title: An Evaluation of Possible Relationships Between Solar Activity and Tree-Ring Growth in Western North America

Summary:

This grant was used to complete a research project originally started with NASA support (NGR-03-002-101).

The objective was to determine whether long tree-ring series could be used to extend the record of sunspot numbers into the past, prior to the first systematic observations of solar activity. Such an extended record would be potentially useful for improved prediction of future levels of solar activity.

Power spectrum and cross-power spectrum analysis, the harmonic dial, digital filtering functions, and principal component analysis were used separately and in combination. Tests were made to determine the possible association between tree-growth variability in western North America and the variation in sunspot numbers since 1700. Special attention was paid to any possible tree-growth response to oscillatory solar variation, including the well-known 11-year rhythm, the 22-year "double cycle" and a proposed 179-year cycle related to planetary motion. In addition to analysis of individual tree-ring chronologies, the study included the comparison of solar variation with the changing magnitude of characteristic regional patterns of tree-growth anomalies. Based on principal component analysis, these functions reflect large-scale patterns of climatic variation.

The results of our investigations show no evidence of significant, consistent relationships between tree growth and solar variation. We conclude

that a continued search for such empirical associations is likely to be unrewarding. However, with the development of more powerful analytical tools, and with the continuing improvement in our understanding of the effects of climate on tree growth, tree rings should become increasingly important as a source of information on past climates, available for the testing of solar-climatic models that may be proposed on geophysical grounds.

Publications:

LeMarche, V.C., Jr. and Fritts, H.C., in press, "Tree Growth and Solar Variation", Second International Symposium on Solar-Terrestrial Relationships in Physical Chemistry and in Life Sciences, Presses Academiques Européenes, Brussels.

LeMarche, V.C., Jr., and Fritts, H.C., in press, "Anomaly Patterns of Climate Over Western United States, 1700-1930, Derived from Principal Component Analysis of Tree-ring Data", Monthly Weather Review.

Grant Number 46. January 4, 1968 $8,660

Principal Investigator Harold L. Johnson, Professor
Lunar and Planetary Laboratory

TITLE: JHKLM Photometer

Summary:

This grant was cancelled.

Grant Number 47. March 13, 1968 $3,500

Principal Investigator: Vern R. Johnson, Professor
Department of Electrical Engineering

Title: Establishment of an Accoustic Transducer Fabrication Facility

Summary:

The purpose of this project was to establish a thin-film fabrication capability which can provide piezoelectrically active thin-films of such materials as cadmium sulfide. These films will be used in conjunction with research conducted in the fields of phonon-photon and phonon-electron interactions in crystalline materials.

The research conducted as a result of this grant has been very fruitful and has resulted in the establishment of the proposed facility as well as being very helpful in obtaining an NSF Initiation Grant (No. GK-3663) in the field of quantum electronics.

This project resulted in a Master of Science thesis by Edward J. Staples, Jr., which is now on file in the University of Arizona Library.

Publications:

A copy of the abstract of E.J. Staples, Jr., Master of Science thesis is included in this report.

Grant Number 48. April 3, 1968 $760.00

Principal Investigator Anton M. J. Gehrels
Lunar and Planetary Laboratory

Title: Observing Session at the Cerro Tololo Observatory

Summary:

The primary objective was to obtain a precise lightcurve of at least 7 hours for Trojan Hektor.

The work proposed for this Grant is now completed with the return of the Principal Investigator from Chile. The observing run was completely successful.

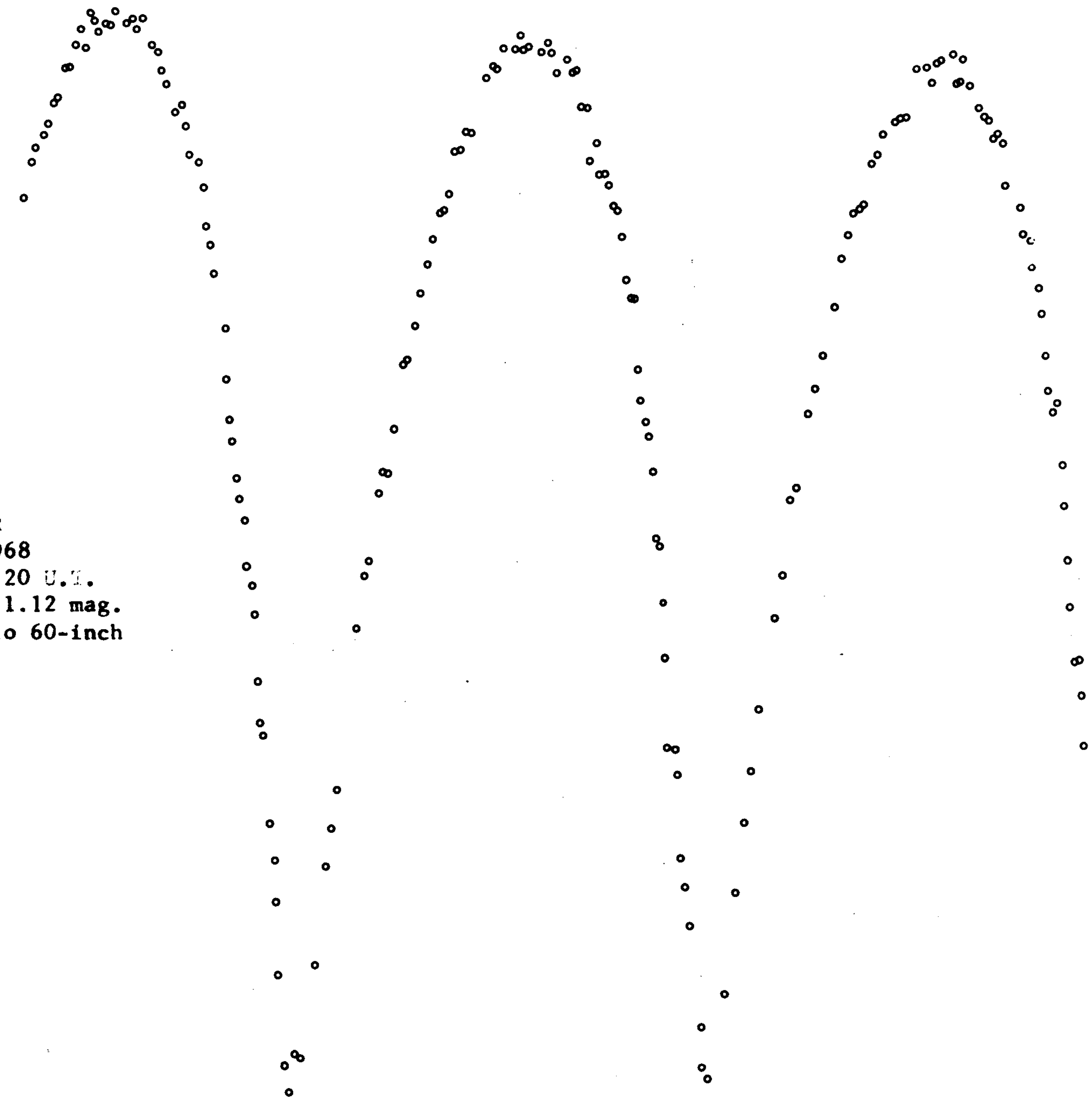
Plates were taken with the Schmidt telescope in order to facilitate the work at the 60-inch reflector. In addition, survey plates of Trojan asteroids and Jovian satellites were taken in a joint program with the Leiden and Cincinnati Observatories. The plates will be sent to Dr. and Mrs. C. J. van Houten in Leiden for further processing.

With the 60-inch, the attached lightcurve was obtained of Trojan Hektor (asteroid #624). The light variation is nearly one magnitude, and the observations were made between 0^h10^m and 9^h20^m of May 1, G.M.T. In addition to the attached lightcurve, and a lightcurve of Hektor separately on another night, precise photometry of colors on the UBV system was obtained during the lightcurve maxima and minima. In a third night, a lightcurve was obtained for Trojan asteroid #1437. The details of the lightcurve work will be further processed with support from a grant from NASA Headquarters, as a continuation of our asteroid work.

A colloquium on asteroid lightcurves was presented at the University of Chile in Santiago. Preparatory discussions for our more extensive 1969 expedition to Cerro Tololo were held with the Observatory Director and with APSA Aerolineas Peruanas (in Lima, Peru).

Publications:

Dunlap, J.L. and Gehrels, T., "Minor Planets. III. Lightcurves of a Trojan Asteroid", Astronomical Journal 74, No. 6, 796.



HEKTOR
1 May 1968
0:10 - 9:20 U.T.
Amplitude 1.12 mag.
Cerro Tololo 60-inch

Grant Number 49. April 3, 1968 $1,749.50

Investigator Dr. Dale P. Cruikshank
Lunar and Planetary Laboratory

Title: Photographic Spectroscopy of Volcanic Flames

In order to obtain new data on the chemical elements and compounds in volcanic flames, the Lunar and Planetary Laboratory has constructed a small field spectrograph. The instrument has an F/2 camera and gives dispersion 50 A/mm. Another long focal length camera and a quartz camera for the ultra-violet have been constructed. This instrument gives higher dispersion and spectral resolution than other instruments used in volcanic flame spectroscopy in the past. It has been hoped to provide data on the chemical reactions occurring in regions of high pressure and temperature; gas collection techniques have previously given information on reactions at or near the surface where combustion in air disguises the character of the original gases.

Two trips have been made to the Hawaiian volcano Halemaumau which began erupting November 5, 1967. Spectra were obtained on both of these trips which are nearly overwhelmed by the continuous black-body radiation of the hot lava, but a few emission lines and bands are seen. During the eruptive phases when the spectra were taken, flames were rare and the source for the spectra consisted of a huge, upwelling fountain of molten lava in the central lake of Halemaumau. Sodium lines, a band of S_2, and a band of CO, and two bands of N_2 are present, superimposed on the continuum. There are also several bands and lines as yet unidentified. The N_2 bands are of particular interest because they represent transitions in the 9-10 eV energy range, while the temperature of the lava at the surface yields energies less than 10 percent of this value.

It therefore seems that detailed analysis of these and other spectra will provide information on certain reactions that occur at depth in the volcanic column, where pressures and temperatures are higher.

Also of interest is the absorption spectrum of the fume emitted by the volcano, much of which is sulfur dioxide and water vapor. A Soviet astronomer has found absorptions in volcanic fumes similar to those he sees in the spectrum of Venus, but these results need detailed confirmation with data that can be obtained with the present equipment. Dr. Cruikshank has this instrument with him at the present time in Hawaii where he will work to obtain this additional data.

Grant Number 50. April 3, 1968 $10,000
(See also Grant Number 76)

Investigator Aden B. Meinel
Optical Sciences

Title: Thin Films Laboratory

Summary:

This grant was issued to cover partial costs of preparing special laboratories and moving the Optical Sciences Center coating facilities from the Space Sciences Building to the Optical Sciences Engineering Annex on 22nd Street. Contract for the necessary construction was awarded in June 1968 and the move into the new Laboratory was completed on October 15, 1969.

Several grants have been given by the Space Sciences Committee from NASA institutional funds to relieve the Optical Sciences Center equipment and staff of a sizeable load of small projects for NASA-supported tasks on campus.

The initial grants were used to purchase a Consolidated Vacuum Corporation Model CV-18 Vacuum Evaporator including accessories. This unit was received in January 1968 and has been in much use since by Dr. Slater for his Multispectral Sensor System task under NAS 9-7081, LPL, Steward Observatory, Electrical Engineering and Physics. We have added to the capability of the basic vacuum system so that precision multilayer stacks can now be done. Funding for the improvement came from the OSC basic contract, USAF F04697-67-C-0197.

Grant Number 51. May 6, 1968 $4,520
(See also Grant Number 19)

Investigator D. M. McEligot, Principal Investigator
H. C. Perkins, Jr., Co-investigator
Aerospace and Mechanical Engineering

Title: Forced Turbulent Flow with High Energy Transports Rates

Summary:

The objective of this work is to find a useful generalization of transport phenomena in turbulent flows. The main difficulty in prediction is no longer in the mathematical approach, but rather in describing the basic turbulent behavior in a form which will be valid as the flow conditions change radically across and along the fluid stream. For strong heating of gases, experimental trends have been predicted, including an unusual wall temperature maximum near the immediate thermal entry, and magnitudes are of the proper level. However, there is apparently a failure to adequately include the history of the turbulent growth in the basic model. Such difficulties may be expected to occur in any analyses which attempt to treat turbulent flows undergoing readjustment - either due to changes in the fluid properties by heating or due to changes in the cross section of the flow passage.

Numerical analyses also have been conducted for turbulent flows readjusting toward laminar behavior. In comparison to several experiments, an additional treatment of growth and decay appeared to yield significant improvement for relaminarized flows. Flow in both circular tubes and non-circular ducts of infinite aspect ratio have been treated under this project.

Publications:

D.M. McEligot and C.A. Bankston, "Numerical Predictions for Circular Tube Laminarization by Heating", ASME paper 69-HT-52, presented at National Heat Transfer Conference, August 1969.

C. A. Bankston and D. M. McEligot, "Turbulent and Laminar Heat Transfer to Gases with Varying Properties in the Entry Region of Circular Ducts", Int. J. Heat Mass Transfer, 13, 319-344 (1970).

D. M. McEligot, C.W. Coon and H. C. Perkins, "Relaminarization in Tubes", Int. J. Heat Mass Transfer, 13, 431-433 (1970).

K. W. Schade and D. M. McEligot, "Cartesian Graetz Problems with Air Property Variation", Int. J. Heat Mass Transfer (in press - no copy available yet).

Grant Number 52. May 6, 1968 $3,400

Investigator Paul H. Skinner
Auditory Research Laboratory

Title: Research in Audiology

Summary:

NASA Institutional support was utilized to procure the special equipment to initiate the above project.

A new technique was developed to study changes which occur in pitch perception over time when the auditory system is exposed to intermittent and continuous fatiguing stimuli. This technique was used to evaluate per-and poststimulatory fatigue in pitch perception to gain knowledge on information processing in the auditory system (auditory theory) and damage-risk-criteria relevant to exposure to different sound levels.

A research grant application was submitted to NIH to continue this research but the application was approved without funding.

A considerable amount of research remains to be done on this project but we lack enabling funds to do so.

Publications:

Paul H. Skinner, "Tracking the Pitch of Pulsed and Continuous Tones", International Audiology, Vol. IX, No. 1, 5-10, January 1970.

Paul H. Skinner and Frank Antinoro, "Perstimulatory Tracking in Pitch Perception at Different Sensation Levels", The Journal of the Acoustical Society of America, Vol. 46, No. 2 (Part 2), 426-430, August 1969.

Paul H. Skinner and Frank Antinoro, "Study of Per- and Poststimulatory Fatigue in Pitch Perception", The Journal of the Acoustical Society of America, Vol. 44, No. 5, 1423-1427, November 1968.

Grant Number 53. May 7, 1968 $2,008

Principal Investigator William K. Hartmann
Lunar and Planetary Laboratory

Title: Early History of Planetary Systems

Summary:

This grant was used to support and publish a considerable amount of lunar research. The extensive Lunar and Planetary Laboratory collection of lunar photos by the NASA Lunar Orbiter was used as basic data. The research involved measuring and counting of craters in different provinces of the moon, which are distinguished by their different ages and different crater densities. Lunar province ages were determined in some of the research.

The program may be judged as successful in that the resulting lunar time-scale so derived has been referred to by various investigators who studied the first rock samples brought back from the moon. I have given several invited presentations of the work, including talks at a Cal Tech conference on origin of planets, and a conference of Apollo investigators at the Manned Spaceflight Center in Houston. The program also served as groundwork for my present project, funded by NASA/Jet Propulsion Lab, to study the craters of Mars in a similar way.

Publications:

W.K. Hartmann, "Lunar Crater Counts, III: Post Mare and 'Archmidedian' Variations", LPL Comm. No. 116, Dec. 1, 1967.

W.K. Hartmann and F.G. Yale, "Lunar Crater Counts, IV: Mare Orientale and Its Basin System", LPL Comm. No. 117, Feb. 1, 1968.

W.K. Hartmann, "Lunar Crater Counts, V: Latitude Dependence and Sources of Impacting Bodies", LPL Comm. No. 118, Mar. 1, 1968.

W.K. Hartmann, "Lunar Crater Counts, VI: The Young Craters Tycho, Aristarchus, and Copernicus", LPL Comm. 119, Mar. 15, 1968.

W.K. Hartmann and D. H. Harris, "Lunar Volcanic Eruiptions Near Aristarchus", LPL Comm. No. 121, July 26, 1968.

W. K. Hartmann, "Preliminary Note on Lunar Cratering Rates and Absolute Time-Scales", Icarus, 12, 131-133 (1970).

W. K. Hartmann, "Terrestrial, Lunar, and Interplanetary Rock Fragmentation", Icarus, 10, 201-213 (1969).

Grant Number 54. June 12, 1968 $5,720

Investigator A.M.J. Gehrels
Lunar and Planetary Laboratory

Title: Theoretical Study of Light Scattering by Small Particles

Summary:

This grant was made to cover the work on interstellar polarization by Dr. G. A. Shah, a theoretical expert of the Mie-van de Hulst theory of light-scattering by small particles.

The work of Dr. Shah helped formulate IBM 1130 computer programs on light scattering by molecules and small particles.

After Dr. Shah went back to his native India, the work was continued by D. L. Coffeen and B. H. Zellner, and also by Dr. Kruszewski who concentrated on light scattering by small particles in circumstellar envelopes.

Publications:

No specific paper resulted, nor was one proposed, but the grant filled a need basic to the continued studies of our polarization group.

Grant Number 55. July 10, 1968 $10,000

Investigator Douglas J. Hamilton
Electrical Engineering

Title: Electro Thermal Interaction in Integrated Circuits

Summary:

Work supported by the above fund has had three principal objectives:

1. Design of heaters and sensors for electrothermal circuits.
2. Analysis of signal processing capability of any given geometrical configuration of electrothermal circuit.
3. Application of electrothermal circuits to signal processing systems.

1. Design of Heaters and Sensors: Every electrothermal circuit includes one or more heaters and one or more sensors. These heaters and sensors are essentially transducers which convert an electrical signal to a thermal signal, and vice-versa, respectively. They may consist of a single element, such as a resistor, a diode, a transistor, or combinations of these. The evolution of a design theory for heaters and sensors involves research in two areas:

a. Thermal Behavior of Integrated Circuit Components: The thermal behavior of basic integrated circuit components has been characterized by the use of electrothermal models. These models are network-like in form, and they therefore enable one to calculate the effects of temperature on the behavior of a complex circuit in the same way that one would analyze an electrical network. This can be done either by hand calculations, for simple circuits, or by computer-aided analysis where it is warranted by complexity. Devices which have been characterized are the bipolar transistor, diffused resistor, junction capacitor, junction-gate field-effect transistor, lateral pnp transistor, Zener diode, and the six integrated diode configurations. Experimental results have been obtained for all of these except the junction capacitor. The measurements involved were made on devices fabricated specifically for that purpose in the Solid State Engineering Laboratory.

b. Evaluation of Heater and Sensor Circuit Configurations: A general method of characterizing electrothermal structures which have one dimensional behavior was developed. The method is similar to the two-port characterization of electric networks. General two-port representations for both heater and sensor circuits have been derived, and performance criteria have been established and calculated for the most useful of the conventional heater and sensor circuits. The differential sensor circuit, an extremely useful configuration for filtering applications, has also been analyzed.

2. Analysis of Electrothermal Signal Processing: A general analysis method has been developed which enables the calculation of the time-dependent temperature distribution on the chip, as well as the transfer function of an electrothermal circuit with any given surface arrangement of lumped and distributed heaters and sensors. A computer program has been written to implement the latter analysis.

In the laboratory a monolithic circuit was fabricated consisting of an array of isolated transistors which can be interconnected in a number of different ways to produce electrothermal filters with diverse properties. Measurements were made for five different configurations, and compared with the results of the computer analysis. The agreement was very good.

A lumped model was derived for a general electrothermal circuit; the principal value of such a model lies in the calculation of the effects of bonding wires, or other externally applied constraints, on the behavior of the circuit.

The general properties of electrothermal transfer functions were studied, with a number of interesting results; the most important being:

a. Rational transfer functions can be approximated by controlling, for example, the geometry of the heater.

b. The gain-bandwidth product for a rational single-pole transfer function depends on the total thermal capacity of the chip, and on the conversion gains of the heater and sensor.

c. Several independent filters can be realized on the same chip.

From the study of transfer-function properties, a practical synthesis procedure was evolved for electrothermal filters. The procedure is implemented by a computer program, and experimental results have been obtained which verify the usefulness of the procedure.

3. Application of Electrothermal Circuits: Three specific applications of electrothermal circuits have been considered: an AGC filter, temperature stabilized substrates, and a frequency selective amplifier.

a. Automatic Gain Control: A monolithic AGC electrothermal filter was designed and fabricated in the Solid State Engineering Laboratory. The filter transfer function had to be specifically designed to avoid instability; this was done by using the synthesis procedure described above. Experimental measurements show good agreement with the performance predicted by the analysis.

b. Temperature Stabilized Substrates: Electrothermal circuits are used in commercially available integrated circuits to stabilize the chip temperature in the presence of ambient temperature variations. This is done in order to reduce the effective temperature coefficient of critical components. A general method of analysis was developed for electrothermal circuits which are used to control temperature coefficients. From the results of such an output voltage, a simple monolithic circuit was fabricated to verify the results of the analysis; excellent agreement was obtained between experimental and theoretical results.

c. Frequency Selective Amplifier: Although this work was not supported by the above fund, it is reported here because it is part of our general effort in electrothermal circuits, and it is closely related to the above topics.

A new system configuration was developed which realizes frequency-selective amplification by the frequency-translation of a low-pass filter characteristic. An electrothermal circuit is used as a low-pass filter with cutoff frequency of 20 Hz. By means of a local oscillator and two channels of analog multipliers, the low-pass characteristic is translated to a center frequency which is that of the local oscillator, in this case 20 KHz. The result is a filter with center frequency 20 KHz and total bandwidth 40 Hz, or a Q of 500. Although frequency-translation techniques are not new, the present system provides the novel feature of insensitivity of Q to phase of quadrature oscillator signals.

The entire system uses no inductors. Excluding the local oscillator and quadrature circuits, which might be common to several filters, it can be fabricated entirely from bipolar transistors and low-value resistors. Thus it is well-suited to monolithic integrated circuit technology.

The filter described above was fabricated in hybrid form to test feasibility. Experimental results agree well with theoretical predictions.

4. Other Results: Although the technical results cited above are certainly important, even more important is the educational product of the work. The total effort in electrothermal circuits during the past two years has produced three Ph.D. degrees. Two of these students were supported on the above fund as half-time research associates: Paul R. Gray and Anthony R. Fletcher. The third was not supported by the fund but was part of the electrothermal circuit research effort; this was Miles F. Friedman, a Hughes Doctoral Fellow who did the research on frequency selective amplification.

In addition to the work reported herein, enough topics for future work in electrothermal circuits have been delineated to occupy two Ph.D. students. A proposal is now being written to request financial support for this for an outside agency.

We would like to express our gratitude to NASA and the University of Arizona Space Sciences Committee for their support of this work.

Publications:

A. R. Fletcher, "Performance of Integrated Electro-Thermal Circuits", Ph.D. Dissertation

M. F. Friedman, "Monolithic High Q Band-Pass Filters Employing Electro-Thermal Circuits", Ph.D. Dissertation

P. R. Gray, "Electro-Thermal Integrated Circuits", Ph.D. Dissertation

P.R.Gray and D.J. Hamilton, "Analysis of Electrothermal Integrated Circuits", 1970 IEEE International Solid-State Circuits Conference

M.F. Friedman and D. J. Hamilton, "An Integrated High-Q Bandpass Filter", 1970 IEEE International Solid-State Circuits Conference

P.R. Gray and D.J. Hamilton, "Analysis of Electrothermal Integrated Circuits", preprint for IEEE Journal of Solid State Circuits

Grant Number 56. July 10, 1968 $7,500

Investigator R. M. Kalbach
Physics Department

Title: Construction of a Digitized Chamber

Summary:

Funds granted for this work were used to purchase the following items of capital equipment:

1 Quad Scalar
1 In/out driver
1 Card bin
1 Control Unit
2 Integrating Zero Crossing discriminators
1 Incremental tape control
1 Incremental tape recorder

These instruments, together with others purchased with funds from other grants and state funds, were assembled into a small, four component wire spark chamber telescope system for use in connection with our Cosmic Ray Research Program. The telescope underwent initial tests in which spark and fiducial pulses were successfully digitized, recorded on magnetic tape, and re-read.

Recently, the system has been expanded to a six-component chamber telescope, the readout system is being prepared for interfacing with a PDP-5 computer, and software programs are being prepared to reconstruct particle trajectories on-line.

People directly involved in this effort included:

1. R. M. Kalbach, Principal Investigator
2. Alburt Pifer, Faculty member
3. Richard Rothschild, Graduate student
4. Dan Davidson, Graduate student
5. Chuck Simmons, Electronics Technician
6. Richard Newman, Programmer
7. Bradford Barber, Graduate student

Grant Number 57. June 13, 1968 $7,313
(See also Grant Number 28)

Investigator John O. Kessler
Department of Physics

Title: Research on Liquid Crystals - Continuation

Summary:

See Final Report on Grant Number 28.

Grant Number 58. October 7, 1968 $4,500
(See also Grant Number 66)

Investigator R. H.Chambers
Physics Department

Title: Construction of an Infrasonic Decoupler Platform

Summary:

The infrasonic decoupler platform is a device designed to decouple extremely sensitive strain measuring instruments from the horizontal components of ambient man-made and natural microseisms. A description of the device is given in the initial proposal (September 6, 1968).

The device is now essentially completed and is presently being put through a series of tests. Preliminary tests show that the platform acts as a bandstop filter for horizontal components of Earth motion in the frequency band from 10^{-1} to 300 Hz; at least 60 db attenuation is obtained in the bandstop frequency region.

With the platform tuned for 60 second period, a system mechanical Q of ~5 is obtained which makes external damping unnecessary.

It is estimated that the platform will be ready for regular use by June 1971. It is scheduled to be used in a series of liquid He^3 experiments aimed at investigating the modulus defect anomaly in fcc metale below 3K.

Publications:

A publication describing the isolation platform is in preparation.

Grant Number 59. October 7, 1968 $3,000

Investigator John O. Stoner
Physics Department

Title: Accurate Measurement of Wavelengths and Line Structures in the Balmer Spectrum of Atomic Hydrogen

Summary:

This is the final report for work done under my direction, as described in my proposal "Accurate Measurement of Wavelengths and Line Structures in the Balmer Spectrum of Atomic Hydrogen", and supported by the NASA Institutional Grant.

This support began with a grant of $3,000 on September 30, 1968 (fund number 5601-525-719-59); after these funds were exhausted your Committee provided another $2,000 on March 12, 1969 (fund number 5601-525-719-67), part of which was withdrawn later. This financial support was used almost entirely to pay for machine shop work. With this help we have completed the following:

a. Fabry-Perot spectrometer: A pressure chamber, manifold, and etalon assembly to be used as a high-resolution spectrometer have been completed. These items, which are to be used in conjunction with the equipment described below, have been working satisfactorily for several months.

b. Hydrogen beam apparatus: An atomic hydrogen beam is formed in a high-capacity vacuum system by collimating atoms dissociated in a tungsten oven. The necessary high flow rates and good collimation have been obtained.

c. Electron gun: After unsuccessful attempt to use a commercially-made electron gun, we built our own, which is now working satisfactorily.

d. Matching optics: Light is extracted from the electron beam-hydrogen beam intersection with the use of a conical reflector (axicon). We have built the optical apparatus necessary to match the light coming from the axicon into the Fabry-Perot spectrometer.

Personnel associated with the project are: John O. Stoner, Jr., Associate Professor and Principal Investigator, and David Ashby, Research Assistant, graduate student.

Grant Number 60. October 8, 1968 $1,146

Investigator G. V. Coyne, S.J.
Lunar and Planetary Laboratory

Title: Photometry and Polarimetry during the Lunar Eclipse of October 6, 1968 at Mauna Kea, Hawaii

Summary:

This grant was used for support of an expedition to the U.S. Weather Observatory at Mauna Loa, Hawaii (this was a more favorable site than the Mauna Kea Observatory) in order to observe the lunar eclipse of October 6, 1968.

The instrument used was an automatic photoelectric polarimeter which was a design study model for spacecraft application. As a guest of ESSA, Dr. Coyne observed for six nights, three before and three after the lunar eclipse, and the polarimetric results have been published in the Astronomical Journal. These observations, carried out to phase angles as small as 0.4 degrees, have helped substantially in determining the nature of the negative branch of the lunar polarization curve. No appreciable increase in the polarization at totality was found, although such an effect has been found in other eclipses. Mr. Charles KenKnight is continuing the photometric reductions of the data, which has required detailed and lengthy calibration procedures.

Publications:

G. V. Coyne and S. F. Pellicori, "Wavelength Dependence of Polarization. XX. The Integrated Disk of the Moon", Astron. J. 75, 54, 1970.

Grant Number 61. October 8, 1968 $1,715

Investigator A. M. J. Gehrels
Lunar and Planetary Laboratory

Title: Improvement of Polariscope Optics

Summary:

It was proposed to improve the optics of the Polariscope 28-inch balloon telescope from about 20 to 2 arcseconds. This is a problem of research interest as well and was to be executed by the Optical Shop of the Optical Sciences Laboratory.

The primary mirror of the Polariscope 28-inch telescope was improved, according to the reports made by Mr. Donald A. Loomis after tests in the Optical Shop.

Grant Number 62. November 6, 1968 $1,430
(See also Grant Number 44)

Investigator Keaton K. Keller
Nuclear Engineering Department

Title: Proton Scattering Microscope

Summary:

This Grant was supplemental to the funds granted under Grant Number 44 when it was found that there would be insufficient financial support to complete the proton scattering microscope.

The Nuclear Engineering Department was able to do the machining and welding of the components collected under Grant Number 44, but it was found that there was a need for a Varian Vacion pump and its control unit; and the glass viewing window would have to be equipped with a variable position. The Investigator contributed at least 8% of his time to this work. The Nuclear Engineering Department contributed $1,000 to the project.

Currently the device, minus the components listed above, is being assembled in the Engineering Building, and testing will start after these additional parts are procured.

Grant Number 63. December 5, 1968 $10,000

Investigator Bartholomew Nagy, Professor
Geochronology Department

Title: Remodeling Laboratories in the Space Sciences Building

Summary:

The Organic Geochemistry Laboratory presently located in Rooms 523, 527, 529, 531 and 533 of the Space Sciences Building was moved from the University of California at San Diego to the University of Arizona in August 1968.

This laboratory under the direction of Dr. Bartholomew Nagy was equipped by NASA with the most modern and sophisticated instrumentation for establishment of a specially clean organic geochemistry laboratory for the purpose of analyzing the returned lunar samples, carbonaceous meteorites, and the oldest known rocks on earth.

In addition to Dr. Nagy, who has been one of the Principal Investigators on the Apollo 11 and 12 lunar projects and will continue as a Principal Investigator on the Apollo 14-19 missions, the laboratory is presently authorized three Research Associates, three Research Assistants, and a Technical Editor/Secretary.

Grant Number 64. January 20, 1969 $9,500
(See also Grant Number 74)

Investigator Dr. Uwe Fink
Lunar and Planetary Laboratory

Title: A High Resolution Infra-red Spectrometer

Summary:

On January 20, 1969 the above proposal was supported by the Space Sciences Committee for the amount of $9,500. On July 6, 1969, an additional amount of $5,800 was approved. This amount was requested since a more precise cost estimate was made with quotes from manufacturers and the Physics Department shop. Around June 1970 the money remaining in the fund, which was about $500, was taken back by the Space Sciences Committee. A few hundred dollars were returned. The project therefore is not yet finished and the following will describe the progress that has been made.

The two sections of 24" diameter tubing together with their end flanges are lying in the spectroscopy lab ready to be welded. The end plates are in the Physics shop and need to have a few windows and feed-through holes machined. The parts for the vacuum lines together with valves and gauges are available in the spectroscopy lab.

The grating box and its frame, as well as the supporting yoke, shaft, and tangent drive arm, have all been completed. The high precision measuring engine screw has been received. The two high precision tandem angular contact bearings are on order. The mirror holders are completed and two 10" pyrex blanks are on hand. The most expensive item, 4" x 8" grating, is also here. Four slit mechanisms and the LiF prism for the auxiliary dispenser have been purchased.

Still needed are detectors, detector housing, preamplifier and phase sensitive amplifying chopping motor, grating drive motor, and precision reduction gear box, as well as a recording system. The vacuum tube must be reasonably well shock mounted. The precision screw must be supported, and the auxiliary dispensing system must be constructed.

In summary the major components for the spectrometer are available but must be put together. A detection system is completely lacking. I estimate that a minimum of $2,000 are needed to make a skeleton working instrument.

Grant Number 65. January 28, 1969 $3,000

Investigator Lawrence K. Schneider
Department of Anatomy, College of Medicine

Title: The Effects of Various Atmospheric Gas Concentrations on Mitosis, Nucleic Acid Synthesis and Chromosome Morphology of Mammalian Lymphocytes _in Vitro_.

Summary:

This project, designed to analyze the effects of sulfur dioxide gas on kinetics and morphology of opossum lymphocytes _in vitro_, is presently incomplete due to technical difficulties encountered in maintaining growth of these cells in tissue culture. Following my communication of April 8, 1969, the remaining funds were used to purchase additional gas, equipment, animals (including care) and supplies necessary for continuation and analysis of the research. No funds from this grant were necessary for personnel support, nor were any used for travel or publication costs. Certain pieces of equipment which were purchased for, and used in, this project were also used in a study financed in part by the General Research Support Grant of the College of Medicine to investigate the effects of SO_2 on human lymphocytes in culture.

Publications:

The results of this recently completed project will be published early in 1971.

Grant Number 66. March 12, 1969 $4,500
(See also Grant Number 58)

Investigator R. H. Chambers
Physics Department

Title: Construction of an Infrasonic Decoupler Platform

Summary:

See Grant Number 58 for Final Report.

Grant Number 67. March 13, 1969 $2,000
(See also Grant Number 59)

Investigator John O. Stoner
Physics Department

Title: Accurate Measurement of Wavelengths and Line Structures in the Balmer Spectrum of Atomic Hydrogen

Summary:

See Grant Number 59 for Final Report.

Grant Number 68. March 12, 1969 $5,000

Investigator H. C. Perkins
Aerospace and Mechanical Engineering

Title: Transient Flow Experiments

Summary:

A study involving the unsteady flow of a viscous incompressible fluid in the entrance of rectangular ducts has been completed. Both semi-analytical and experimental results for the time to each steady state during flow initiation were achieved for Reynolds numbers ranging from 680 to 63700 using water as the working medium. The duct Reynolds number used is the eventual steady state value, $Re = \rho V_{s.s} D_h / \mu$.

Tests were run with three different aspect ratios in a vertical test section. The aspect ratios were 7.8, 11.4 and 22.2 and the largest aspect ratio was assumed to approximate a parallel plates condition. In addition, results from a quantitative dye study during flow initiation were completed and compared with those results obtained with pressure transducers.

The investigation revealed that the non-dimensional time required to reach steady state for an incompressible viscous fluid, starting from rest, increased as the duct Reynolds number was increased. Conversely, it was found that as the aspect ratio of the duct was increased, the non-dimensional time required to reach steady state decreased. Furthermore, the results at high Reynolds numbers (Re >25000) rather weakly indicate a possible increase in time required to reach steady state with position along the duct irrespective of the Reynolds number or aspect ratio.

A quantitative dye study, based on high speed movie results, for the time to steady state showed excellent agreement with the results generated from

pressure transducer measurements. A qualitative description of the flow field during its transient response showed that the velocity-time relationship of the flow field was the complement of the transient pressure-time curve.

The time required to reach steady state ranged from 260 milliseconds to 1100 milliseconds depending upon the Reynolds number, aspect ratio, and position down the duct. Since steady state conditions were approached asymptotically, the exact time to steady state was difficult to obtain. An analysis of the reduction of data showed the results pertaining to this portion of the investigation to exhibit differences of the order of 10%. The non-dimensional time required to reach steady state as a function of the Reynolds number was found by an empirical curve fit to be of the following form:

$$t\ /D_h^{\ 2} = 0.70 + (0.61 \times 10^{-5}) \times Re + (0.26 \times 10^{-9}) \times Re^2.$$

Research personnel:

Dr. H.C. Perkins — 1 month, Summer 1969 plus 15% during academic year, (no cost).

Mr. Chuck Cartmill — 2 months, Summer 1969 plus full time academic year, (no cost).
(Mr. Cartmill took his Ph.D. orals October 30, 1970. His dissertation has been approved by his committee).

Follow-on-contracts: .

The transient flow project will be continued if a suitable student can be found. Since an experimental apparatus has been completed, costs will be minimal.

Because of Space-Science funding a follow-on-contract in the area of flow visualization has been funded by NASA (NGR-03-002-2131) for $100,000 for February 1970-January 1972. While the work is not directly related to that of the Space Science grant the effort expanded under the Space Science money will be of crucial importance in receiving the NASA grant. The initial suggestion for the transient problem was made by NASA-Lewis and it is this same group that subsequently funded our present grant. The efforts of the Space Sciences Committee are greatly appreciated.

Grant Number 69. March 12, 1969 $30,000

Investigators G. P. Kuiper and Harold L. Johnson
Lunar and Planetary Laboratory

Title: Development of a Flyable High-Resolution Fourier-Transform Interferometer for IR Planetary and Stellar Observations

Summary:

The funds from this grant were used in carrying out modifications of the Block interferometer which was used in approximately 30 high-altitude flights on the NASA CV-990 jet during the period 1967-1969. During the Spring and Summer of 1969 scientific results of signficance were obtained with the modified interferometer. The results of these observations of Mars and Venus have been reviewed in preliminary form at several conferences. Final publication required the development of additional computer programs for the reduction and especially the computation of synthetic spectra of water vapor depending upon temperature and atmospheric pressure. These new developments are now complete and a large publication on the 1969 results is now in preparation.

Grant Number 70. June 2, 1969 $4,880

Investigator Lawrence C. Schooley
Electrical Engineering

Title: Implementation of SCEPTRE Electronic Circuit Analysis Program

Summary:

The summer of 1969 was spent conducting research as outlined in the original proposal. A copy of the SCEPTRE program was obtained from Control Data Corporation, and necessary changes for compatibility with our computer installation were completed by mid-July. At that time, the controlling Government Agency (Air Force Weapons Laboratory, Kirtland AFB) announced that a new version of SCEPTRE was being released and that all old versions would no longer be supported. A copy of the new version was obtained from Kirtland and during the remainder of July and August approximately 80% of the work necessary to make it operational was completed. Sufficient documentation to permit use of the older CDC version was also written.

On October 6, 1969, the CDC6400 computer operating system was changed and the CDC version now will not work without additional program changes for compatibility. No effort will be spent on this unless unforeseen difficulties arise in completing conversion of the new issue of the program.

Informal contact has been made with Bell Aerosystems Corporation, Tucson, regarding a research grant for continued development of SCEPTRE. A formal proposal will be submitted if they receive an anticipated contract award which requires use of the program. Also, I anticipate submitting a proposal for an NSF initiation grant to continue my research in the area of computer-aided design.

Grant Number 71. June 2, 1969 $2,250

Investigator Granino A. Korn
Electrical Engineering

Title: Digital-Computer Graph Plotter Using Inexpensive TV Circuits

Summary:

It was proposed that a remarkably inexpensive digital-computer output plotter, conceived by the Investigator, be designed and built as the basis for the M.S. thesis project of M.S. candidate C. Wiatrowski. The least expensive way for large-screen plotting graphs and coordinate nets is to employ television-receiver displays, which are mass-produced and thus very inexpensive. Using a digital computer and a color television monitor, four curves in four different colors were plotted.

The final results of the research carried out under this Grant are contained in the M.S. thesis by C. Wiatrowski. The display is working nicely and will be incorporated into the DARE console. A copy of the Fall Joint Computer Conference paper on Project DARE has been prepared, as well as a complete list of reports prepared by our Computer Science Research Laboratory.

Publications:

C.A. Wiatrowski, "A New Color-Television Graph Plotter for Digital Computers", M.S. Thesis.

CSRL Memo No. 139/R69-2, "List of CSRL Publications".

G.A. Korn, "Project DARE: Differential Analyzer Replacement by On-Line Digital Simulation", ACL Memorandum No. 168.

Grant Number 72. June 2, 1969. $1,500

Investigator Dr. William G. Tifft
Astronomy Department

Title: NGC Catalogue Program

Summary:

As of September 1, 1970, the Modern Version of the New General Catalogue is estimated to be 95% complete. All basic data was punched onto computer cards and has been compiled onto a master magnetic tape. A small amount of data editing remains and the final decisions concerning print format for publication are incomplete. It appears likely that a publication through the U of A Press will be the means of publication.

All funds derived from the institutional grant for this program were expended before the end of 1969. The final phases of this program have been supported under NASA Grant NGR 03-002-032, and all of the subsequent reporting for this program has been incorporated into the reporting under the NASA Grant.

Attached to this report is one copy of a sample printout of a portion of the master tape and a commentary sheet describing the program. This material has been distributed to a number of astronomers for comments prior to placing the master tape in its final edited form. Initial responses to the program have been quite favorable. Preliminary copies of the complete catalogue have already been used locally.

Grant Number 73. July 8, 1969 $4,750

Investigator Vern R. Johnson, Associate Professor
Electrical Engineering

Title: Intra-Cavity Laser Modulation

Summary:

Objectives: The purpose of this research program was to investigate internal laser modulation and output signal coupling via a rotation in the polarization of the laser beam. During the course of this program it was planned to theoretically investigate several techniques for shifting the polarization of a laser beam directly inside the laser cavity; however, particular emphasis was to be placed on using co-linear Bragg scattering caused by a microwave acoustic beam. All of the work has definite engineering applications in optical communications, lidar ranging and tracking, and as a laboratory tool for investigation of the anisotropic propagation and interaction phenomena in various materials.

Results: The diffraction of a plane light wave incident obliquely upon an anisotropic dielectric slab, traversed longitudinally by a plane acoustic wave of approximately the same wavelength was examined by means of a coupled mode approach. This approach lends itself to a wide range of techniques that have already been developed extensively in electromagnetic theory. The approach should also provide a considerable amount of physical insight into the problem.

Initially an input wave was assumed to couple to ordinary and extraordinary output waves. Maxwell's equations were then written in first order form. It might be noted that sets of ordinary and extraordinary waves may be necessary but initially only one of each was assumed. Before proceeding

it was necessary to determine how the acoustic wave changes the dielectric constant of the medium. This perturbation was derived and takes the form of a 3 x 3 matrix. In order to do this a direction in the crystal was picked so that only a plane longitudinal acoustic would propagate. It is this acoustic wave that is used to diffract light.

Maxwell's equations were then written in first order coupled mode form. Solutions for these equations have been obtained, thus completing phase one. Phase two of this project (partial funding for phase two of this project has been provided by an NSF Institutional Grant at The University of Arizona) is concerned with showing that the diffracted field in the region of the crystal and beyond can be described by coupled modes which interact with each other in the presence of the acoustic wave. The coupled equations are also being examined with the view that a transmission line approach may be used, and that equivalent networks may be utilized to account for boundary conditions and other characteristics of the diffracted field. It appears that it is the transmission line approach with its equivalent networks that holds the greatest promise.

This work has provided the basis for a Ph.D. dissertation for Mr. A.E. Hooper. A complete report covering the project will be the dissertation of Mr. Hooper.

Future plans: This work will be expanded and completed under an NSF Grant that was received partially as the result of this research effort.

Outside Support Requested: A one-year grant from the National Science Foundation has been received in the amount of $38,800 to carry out research in Intra-cavity Modulation.

Grant Number 74. July 9, 1969 $5,800
(See also Grant Number 64)
Investigator Dr. Uwe Fink
Lunar and Planetary Laboratory

Title: A High Resolution Infra-Red Spectrometer

Summary:

See Grant Number 64 for Final Report

Grant Number 75. July 8, 1969 $1,600

Investigator A.M.J. Gehrels
Lunar and Planetary Laboratory

Title: Observing Session at Cerro Tololo, August 1969, for Observations of Geographos

Summary:

Geographos was observed with the 60-inch reflector of the Cerro Tololo Inter-American Observatory in August and September of 1969. From lightcurves it was expected to get an approximate idea of the shape and a precise determination of the rate and sense of rotation and of the orientation of the axis in space. Additional polarimetric observations would possibly give indication of the surface reflectivity from which the size could be approximately derived.

Two lightcurves were obtained on Geographos, one of which is shown on the attached page. We have never seen an amplitude as large as this one before on the minor planets. Apparently, Geographos is a very elongated object. There is, however, more information in that lightcurve. The two minima are not at the same level, nor are the maxima, which indicates that there are reflectivity variations over the surface. There are distinct asymmetries in the shape of the lightcurve which also indicate reflectivity and shape irregularities. The period of rotation is 5^h12^m. The epochs obtained at CTIO were essential for our determination of the shape, the precise rate of rotation, and the orientation of the pole. This analysis will follow the example of the one made for Hektor, a reprint of which is provided.

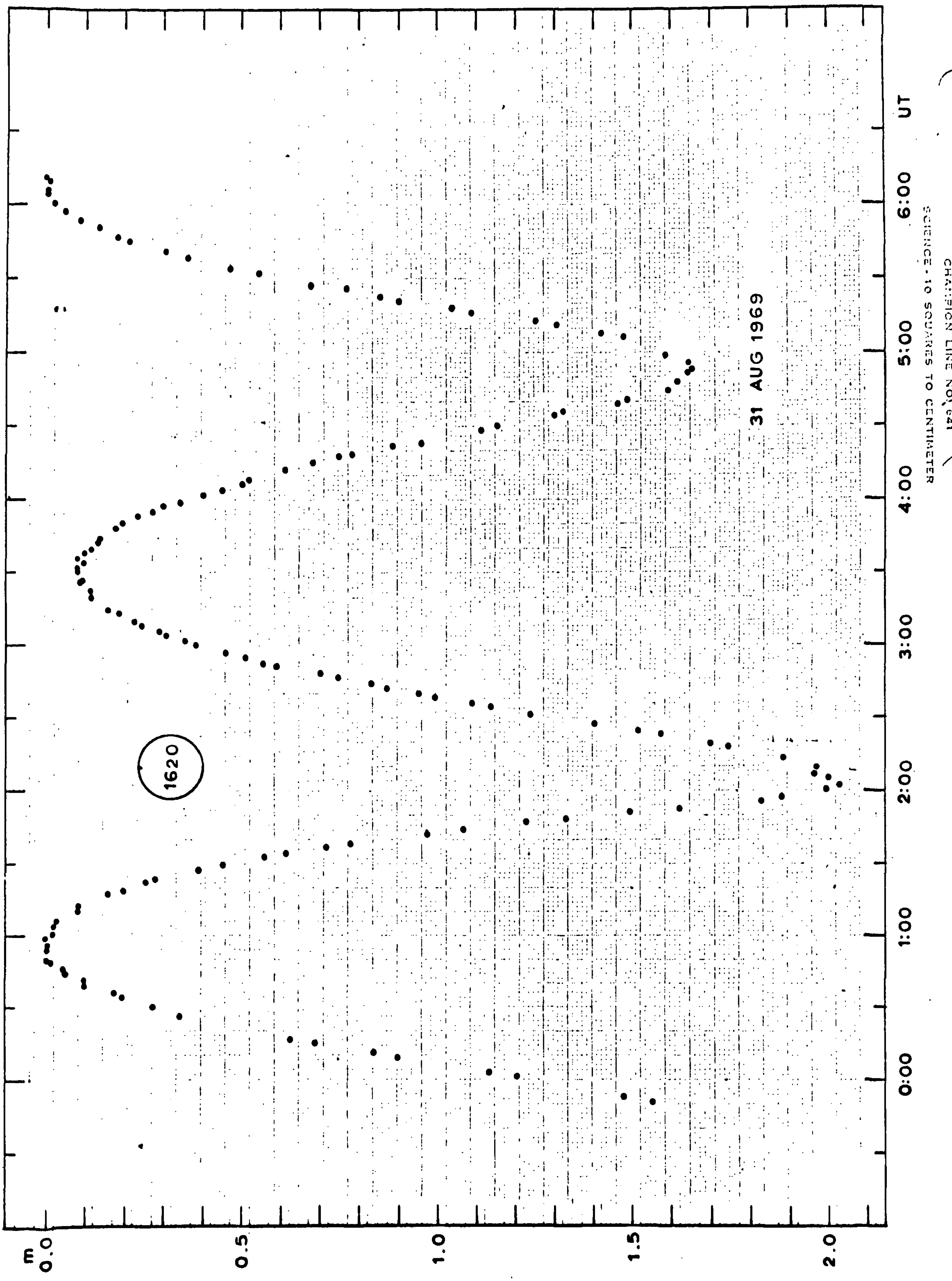
A photometric night at Cerro Tololo allows fine precision. The individual readings of the comparison star used on August 31, 1969 showed an average deviation of less than $\pm$ 0.002 mag from a mean curve through the magnitude-time plot.

The polarization of Geographos was measured on five nights with B and V filters over the phase angle range 78 - 42°. There appears to be only 4% polarization near 78° and this low polarization suggests a fairly high reflectivity.

Thirty-eight selected Mira variable stars were observed for polarization. About 13 of these have appreciable polarizations, in terms of 1 or 2%. Detailed reduction and study are in progress.

Of the grant of $1,600, $1,603.79 has been spent (this amount is not final as yet). The analysis of the observations will take about six months, and is being made with support from NASA (5601-920-669).

We thank the Director and Observatory Staff for their kind and effective cooperation, and the Space Sciences Committee for their financial support.



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Grant Number 76. July 9, 1969 $2,300
(See also Grant Number 50)

Investigator Aden B. Meinel
Optical Sciences

Title: For Operational Support of NASA Thin Films Tasks

Summary:

This was a supplemental grant of $2,300 which was used to support the operating staff of the Thin Films Laboratory set up under Grant Number 50. This amount represented approximately 10% of the work effort of the 22nd Street High Vacuum Laboratory and the NASA-related work orders from campus groups outside the Optical Sciences Center.

Grant Number 77. December 19, 1969 $20,000

Investigator G. P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: Loan for Continued Development of Infrared Interferometry

Summary:

In the light of the rapidly developing field of interferometry and the growing pressure for getting additional data on atmospheric conditions on the planets, efforts were made to acquire an interferometer of intermediate resolution (0.5 cm^{-1}) for high-altitude observations both from aircraft and the highest mountains accessible. As a result of study of the optimum design for such an instrument, it was concluded that the Idealab instrument was definitely superior to any other interferometer of the same resolution already available to the Laboratory.

The Idealab interferometer was purchased in the Spring of 1970. It was found that certain basic structural modifications were necessary and these were carried out by the factory during the Summer. Delivery to LPL was finally accomplished in September 1970 and the instrument is now being outfitted for use at the Cassegrain focus and also aboard high-altitude aircraft. Both of these uses impose rather stringent requirements on all aspects of the experiment. The instrument as purchased was not a completely scientific tool and it has been necessary to outfit it with an optical system which will accept light from a telescope. It must be provided with a digital data system and with an automatic guiding system. An on-line computer for real-time verification of the results is also being added. These modifications and additions are being carried out in the LPL machine and optical shops and it is expected that the instrument will be operational by Spring 1971.

Grant Number 78. December 23, 1969 $3,280

Investigators Dr. Leo Randic and Dr. D. P. Cruikshank
Lunar and Planetary Laboratory

Title: Purchase of Additional Gratings, Solar-High Altitude Spectrometer

Summary:

Because of the fundamental importance of the compilation of earth-based as well as high-altitude solar spectra for all planetary IR spectroscopy, and the value to solar physics itself, it was considered essential to increase the resolution, where feasible, on the Mt. Lemmon solar spectrum runs already obtained. For this program it was necessary to acquire longer gratings, 206 mm instead of 154 mm. Three such gratings were available commercially. (The importance of long gratings is that they can be used at higher inclinations to the incident beam, yet not cause the beamwidth to be reduced so badly that the resolution is thereby cut).

Two of the gratings were purchased and installed in the solar high-altitude spectrometer on Mt. Lemmon, where the above outlined program is now being carried out to maximum advantage. The third grating is on order but has not as yet been delivered. It will be installed and put into operation as soon as received.

Grant Number 79. December 23, 1969 $2,370

Investigators: Dr. R.N. Carlile, Professor of Electrical Engineering
Dr. V.R. Johnson, Associate Professor of Electrical Engineering
Mr. E.W. Rahneberg, Graduate Student
Mr. D.C. Nelson, Graduate Student

Title: Microwave Slow Wave Transmission Systems Employing a Thin Semi-metal Film

Summary:

The purpose of this project was to investigate the electrical properties of thin single-crystal films of bismuth in the microwave frequency range. Specifically, it was desired to measure the permittivity of the bismuth film.

This grant provided partial support for research which resulted in a set of microwave and galvonometric measurements which have provided much information concerning the physical properties of thin-film bismuth. This research also resulted in the fabrication of a laboratory facility for the evaporation of thin bismuth films.

The project resulted in a Master of Science thesis by David C. Nelson, and a Ph.D. dissertation by Eric W. Rahneberg. These papers are now being completed and will soon be on file in the University of Arizona Library.

Publications:

Abstract of M.S. thesis by David C. Nelson, "The Growth and Orientation of Thin Crystalline Bismuth Films"

Abstract of Ph.D. thesis by Eric W. Rahneberg, "Measurement of the Complex Permittivity of Thin Bismuth Film Within the KU-Band".

Grant Number 80. December 23, 1969 $1,065

Investigator Mr. Godfrey T. Sill
Lunar and Planetary Laboratory

Title: Investigate the Processes Responsible for the Clouds of Venus

Summary:

Equipment was obtained to test in the chemical laboratory some hypotheses about the clouds of Venus, and their relationship to the atmosphere and surface of the planet. Both high temperatures and high pressures are needed to simulate the surface of Venus. The high temperature equipment is now operating; the high pressure equipment is in the design and construction phase.

One of the problems to be investigated was the stability of ferrous chloride (the presumed cloud constituent on Venus) at high temperatures in contact with the surface rock to Venus. The most telling experiment involved the reacting of hydrogen chloride (one of the atmospheric gases of Venus) with ferrous oxide (a presumed constituent of the surface rock) in the presence of water vapor and nitrogen (inert ingredient). The N_2 with water vapor and HCl was passed over ferrous oxide in a furnace at 450°C; after a few hours the cool glass outlet tube from the furnace began to show the presence of ferrous chloride tetrahydrate. This occurred, despite the large thermodynamic evidence that it should not have. Of course, the thermodynamic data is calculated for an equilibrium situation, where all constituents equilibrate with each other. But I suggest that the experiment more closely matches the situation on Venus, where an atmosphere would be sweeping across the surface, and bring the ferrous chloride up to higher levels, where we observe the clouds. At least the situation is left open for a mechanism to replenish the clouds of

Venus. When the high pressure equipment is ready for use, the same experiment will be duplicated at conditions more closely approximating the Venus surface.

The same laboratory equipment has been recently used to investigate chemical problems in relation to the colored compounds that exist in the atmospheres of Jupiter and Saturn. It is perhaps a little premature to discuss the results, because the full story is not yet available. But interesting results have been obtained. In general the colors of these planets can be explained by compounds of sulfur. The key compound is sulfane, H_2S_n, where n is 4, 5, or 6. Sulfanes can be produced by the ultraviolet irradiation of H_2S. Sulfanes are yellow, with a spectral response close to the belt of Saturn. On Jupiter, gaseous ammonia can react with sulfane to produce various ammonium polysulfides of orange and dark red hue. The overall colors are good; the problem now is to see if the planets match the spectral reflection of these compounds.

Grant Number 81. March 11, 1970 $2,200

Investigators Dr. G. Van Biesbroeck
Mr. S. Larson
Lunar and Planetary Laboratory

Title: Observation of the Total Solar Eclipse of March 7, 1970

Summary:

The main purpose was the survey of the field surrounding the eclipsed disk in order to locate unknown comets near the sun.

Two cameras were prepared for this purpose: a 12-inch focus f/2.5 lens giving on an 8 x 10 plate a field of more than 22° radius, and a 35-inch focus f/7 medium lens. Both lenses were filtered to record in yellow light in order to reduce the effect of scattered light in the atmosphere. A 42-inch f/7 reflector was added to record the polarization of the corona at different wavelengths. These three elements were carried by a sturdy equatorially driven mounting supported on four adjustable legs.

Also prepared was a movie camera of 35-mm color film to show the Bailey beads and prominences in the inner corona. This was to be used in a fixed position in front of a mirror carried by a heliostat mounting.

All this equipment was loaded in a small U-Haul truck which we drove some 2,000 miles to Perry, Florida, on the central line of the eclipse. I had the help of Mr. and Mrs. Stephen Larson.

The instruments were focussed before departure and exposure times determined by exposing plates on the sky around the time of the February full moon, since it is known that the illumination by the corona is of the same order of intensity as full moonlight.

The weather was rainy during most of our travel to Florida. The day before the eclipse it cleared enough so that the instruments could be properly erected and adjusted on the grounds of the Perry Elks Club, which had been reserved by the American Association of Variable Star observers. The sky remained cloudy through the whole duration of the eclipse. The progress of the darkening shadow was impressive but no record of the eclipse could be obtained. There were a great many observers assembled in Perry, including foreign groups from Germany, Switzerland and Japan, but all were disappointed.

Grant Number 82. March 11, 1970 $562.00

Investigator G. P. Kuiper, Professor and Director
Lunar and Planetary Laboratory

Title: LPL Participation in NASA Venus-Mercury Flyby Mission

Summary:

At the invitation of NASA, this Laboratory has been involved since September 1969 in the planning and organization of a Venus-Mercury Flyby Mission to be launched in 1973, the Venus encounter to take place about February 1974 and the Mercury encounter, April 1974. Participation to date has involved attendance at the Jet Propulsion Laboratory, California, and the preparation of scientific materials (tables, graphs, photographs) on the numerous possible flight approaches, as well as a film system of the type used on lunar Orbiter.

The preliminary planning of this Mission has been completed. This has involved almost monthly trips to California to participate in meetings at JPL. We have evaluated four different imaging systems for the Flyby Mission. This evaluation involved detailed picture taking sequences for each imaging system, the establishment of the scientific objectives of the imaging experiments, and the selection of the experimental objectives. This Mission is now entering the operational phase and our continued participation will be carried on for the next five years under financial support directly from NASA-JPL.

Publications:

Preliminary study of the planet Mercury in preparation for this Mission has resulted in the publication of LPL Communication No. 143, "The Planet Mercury: Summary of Present Knowledge", G. P. Kuiper, 1970.

A paper on the Venus-Mercury Mission is in preparation for publication in *Icarus*, in January 1971.

Grant Number 83. March 11, 1970 $1,500

Investigator Dr. Harold P. Larson
Lunar and Planetary Laboratory

Title: Development of the Idealab Interferometer

Summary:

The purpose of this grant is to design and construct the appropriate electronics, the external optics, and the digital data recording system for use with a real-time Fourier transform computer for planetary spectroscopy.

As stated in the proposal the construction of the real-time Fourier transform computer for use in the Lunar and Planetary Laboratory's Fourier spectroscopy program was not to start until the fall of 1970 (specifically, October 1) at which time the electrical engineer who designed the original device, Mr. Guy Michel, arrived from Laboratoire Aimé Cotton, Centre Nationale de la Recherche Scientifique, Orsay, France, to spend a year at LPL. The amount of the grant has already been spent on electronic items, primarily integrated circuits, included in lists of components forwarded in advance by Mr. Michel. Although the original sum granted, $5,000, was reduced to $1,500, which has temporarily delayed the project, it is expected that the remaining funds will ultimately be found to ensure successful completion of the project.